FINAL REPORT
Georgia Tech Project G-35-611

SOLAR RADIATION STUDIES

By
Lonzy J. Lewis, Principal Investigator

Report Period September 1, 1981 – December 31, 1982

Submitted to
THE NATIONAL OCEANIC and ATMOSPHERIC ADMINISTRATION

Under
NOAA Grant No: NA81AA-D-00097

JUNE 1983

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF GEOPHYSICAL SCIENCES
ATLANTA, GEORGIA 30332

1983

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I. Introduction and Statement of the Proposed Research

Energy received from the sun is the primary driving force for the earth's natural systems. The distribution of solar radiation intercepted by the earth's surface is one of the major factors controlling atmospheric circulation that determines weather and climate. The interaction of gases and aerosols with solar radiation in the earth's atmosphere disturbs and redistributes the radiation passing through the atmosphere. Since the mid-sixties much effort has gone into evaluating the effects of this interaction. The increased emphasis in this area has resulted from two major circumstances: (1) an increased environmental awareness of the possible effects of air pollution on the earth's delicate energy balance (The "Ice Age" scare) and (2) the realization of the severe shortage and increasing cost of traditional sources of energy. These circumstances have caused a resurgence toward the use of the sun as a source of energy and have forced man to make a critical evaluation of his influence on the environment. Within the School of Geophysical Sciences at the Georgia Institute of Technology exists a strong research program concerned with the evaluation of the effects of atmospheric constituents on the amount of solar radiation reaching the earth's surface and on regional and global climate. Better measurement, interpretation, and modeling of solar radiation in the atmosphere are needed.

PROPOSED RESEARCH

Research activities will revolve around solar radiation data measurements, interpretation and modeling, including analysis and measurement of such atmospheric effects as attenuation by aerosols, clouds, and water vapor. The research approach will utilize solar radiation measurements at the Georgia Tech campus, Shenandoah, GA site, and at other sites throughout the southeast region, laboratory and field measurements of aerosol complex index of refraction and other properties, and computer modeling for simulation of solar radiation, especially for solar energy application and regional climate studies. Interactions with NOAA Labs in Silver Springs, Boulder, Oak Ridge, and Research Triangle Park will be augmented by visits to NCAR and SERI (Solar Energy Research Institute) to develop mutual exchange of data and modeling results and interpretations. An initial connection with SERI has already been obtained. Dr. Lewis will conduct research at SERI in the summer 1981 as an appointee of a summer faculty research associateship in the DOE/ASEE Summer Facility Research Program. Research will center on solar spectral measurements and modeling. SERI has developed a spectroradiometer for routine measurement of the solar spectrum. The radiometer measures the spectrum of solar energy between 0.3 and 2.5 microns wavelength in less than 2.5 minutes, with 0.007 μm resolution in the visible (0.3 - 0.88 μm) and a 0.1 μm resolution in the infrared (0.7 - 2.5 μm). The instrument measures direct-beam, diffuse, and global radiation spectra. The complete system is controlled by a minicomputer. The object of this summer research will be to obtain some good spectra under varying atmospheric conditions and to make some detailed comparisons between measurement and theory. Several rigorous radiative transfer models are in use today but these have not been properly verified with spectra data. Some spectra data do exist but these were not accompanied by adequate measurements of atmospheric conditions. Such meteorological measurements will be made at the time of the spectra measurements as part of this research.

In addition to the interactions with major laboratories, shorter visits to regional colleges will develop interactions whose goals will be to attract more minority students into the atmospheric sciences. One such visit, to Jackson State University in Jackson, MS, has already taken place, and proved very successful. As part of this visit our Mobile Atmospheric Research Vehicle (MARV) was utilized to make measurements of a host of meteorological parameters. As part of the mobile research package, a recently acquired tethered balloon system was used to obtain atmospheric profiles of several of these parameters. Examples of profiles obtained during the visit are shown in Figures 1 and 2. Such data will prove to be very helpful when combined with the radiation data, meteorological data, and lidar data in arriving at a much more complete picture of the boundary layer and its effects on solar radiation and climate. MARV will provide large area coverage in assessing the regional variability of the solar resource and the basic atmospheric variables. Such measurements are valuable not only to solar energy applications and climate studies but also in air pollution dispersion studies. Moreover, MARV will continue to serve as a valuable tool in attracting future minority scientists into the atmospheric sciences as it travels throughout the southeast.

As part of the southeast regional interaction in both research and training capacities, Dr. Lewis will assist in setting up some inexpensive but proven accurate solar cell radiometers and integrators (Licor Lambda 200S photocell radiometer and LI 500 printer integrator) at regional colleges. These units, operated on a continuous basis, together with more limited scale

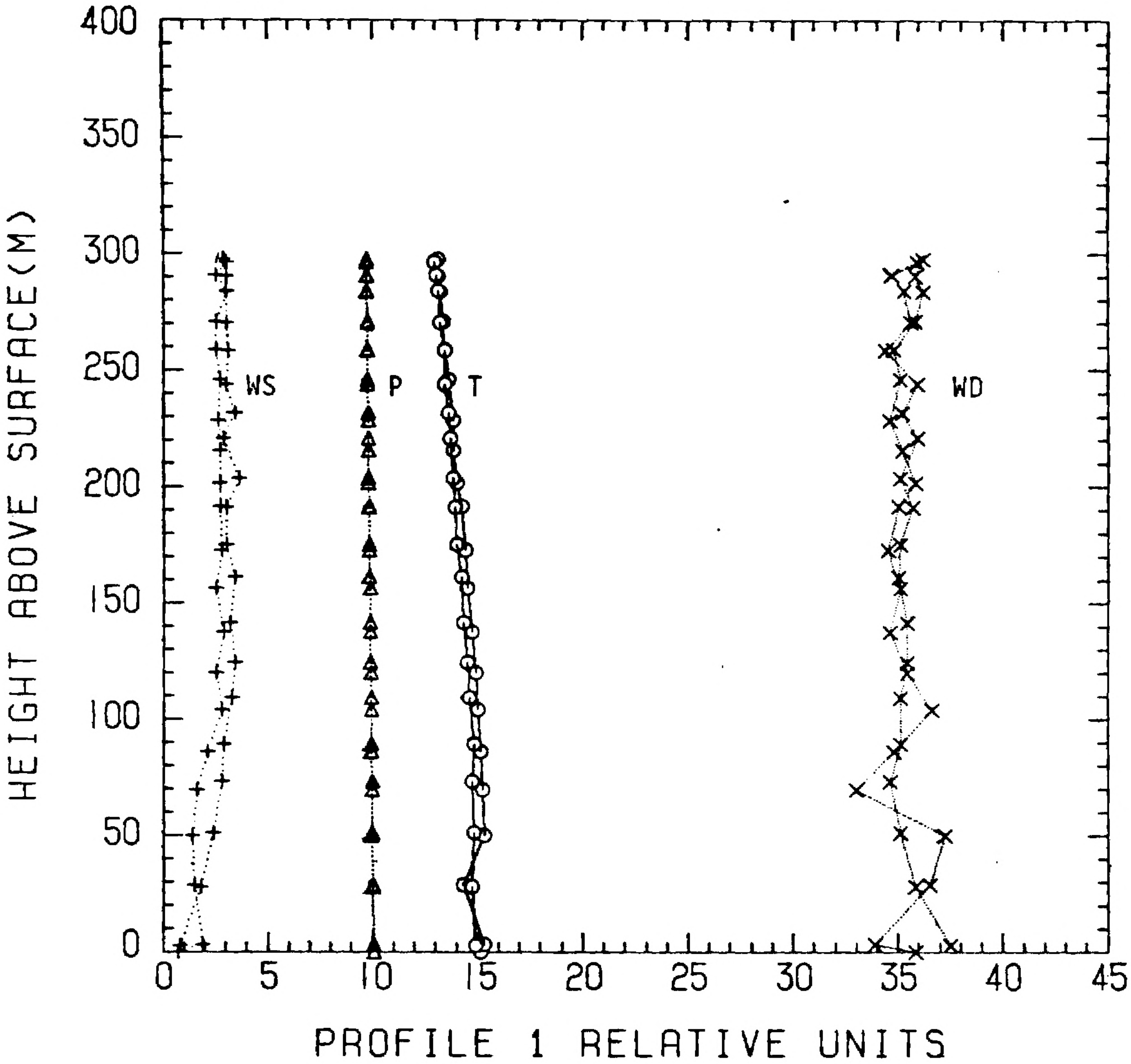

Figure 1. Profiles of wind speed, WS (m/sec)---+; pressure P(10^{-2}mb)--Δ; temperature, T(°C)--O; and wind direction WD(10^{-1} deg)--x taken on 3/24/81 1800-1830 CST at Jackson State University.

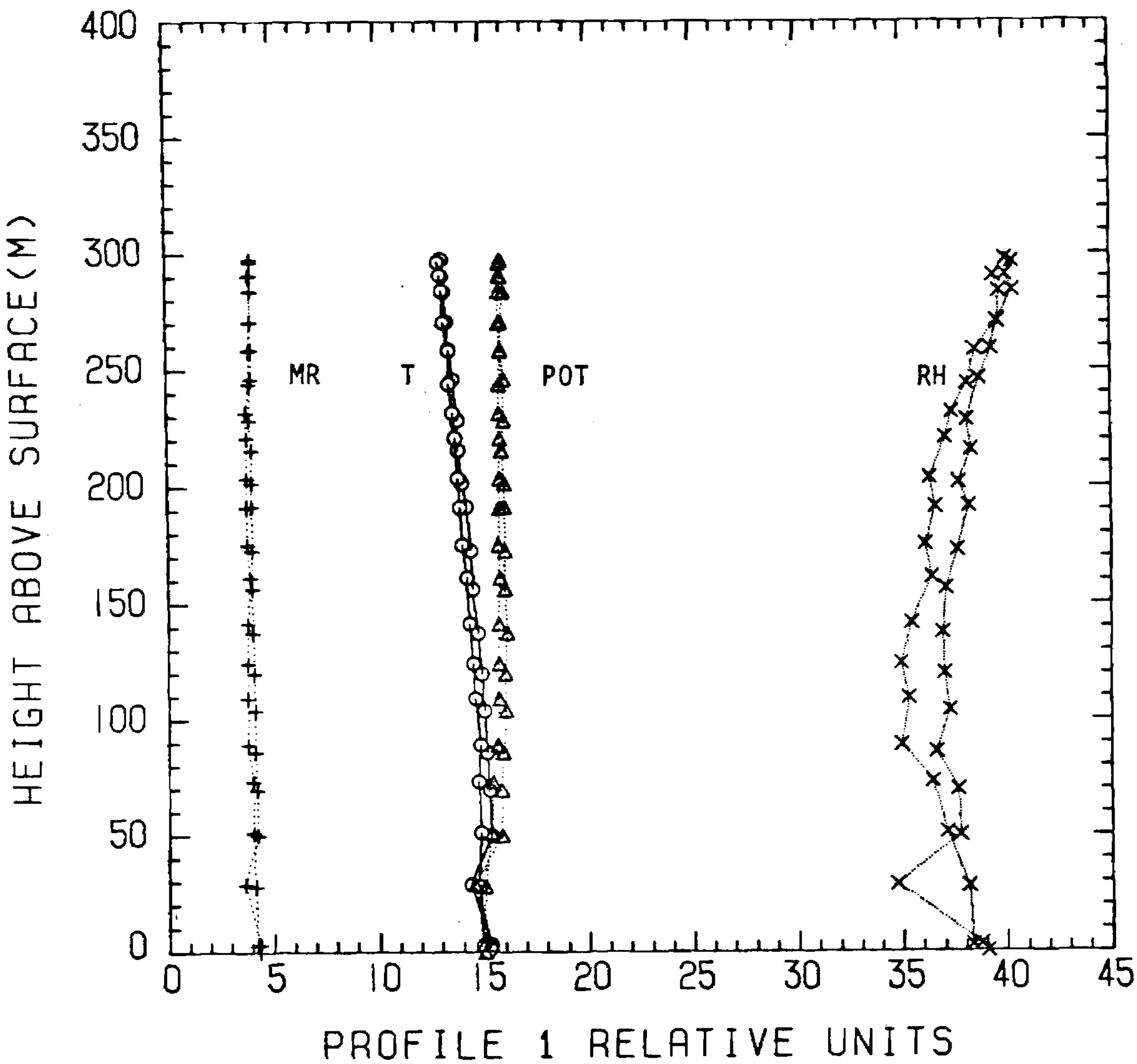

Figure 2. Profiles of water vapor mixing ratio, MR(g/kg)--+; temperature T(°C)--O; potential temperature, POT (°C)--Δ; and relative humidity, RH(%) --x taken on 3/24/81 1800-1830 CST at Jackson State University.

monitoring with the mobile van system, will allow for significant improvement in the regional solar radiation data base, as well as serve as a catalyst for interaction with regional universities on the minority graduate manpower development goals of the NSF/NOAA "Graduate Research Opportunity in the Atmospheric and Terrestrial Sciences" program.

As a special purpose of this proposed research, we would like to develop expertise and experience in the use of available satellite data for the evaluation of the solar resource and the radiative effects of clouds and aerosols on a regional scale. Such measurements have obvious applications in climate studies. Some prior experience with satellite data retrieval and analysis exist among our staff as alluded in Section II-B. Satellites offer unique advantages. Relative to point measurements at the surface, satellite data offer the observational advantage of repetitive coverage, with the same sensors of all geographic areas. Recently data from satellite platforms have been used to estimate mean values of solar insolation (Tarpley, 1979; Gautier, Diak, and Masse, 1980; Hiser and Senn, 1980). These studies seem promising. Tarpley (1979) used solar radiation and cloud data from GOES satellite and correlated these data with surface measurements of insolation made by pyranometers. He employed a statistical method to infer the ground level fluxes. Gautier, Diak, and Masse (1980) employed a simple physical model to infer insolation from the GOES data. We have recently acquired some reduced GOES data from Dr. Tarpley and we have applied his regression model to data obtained here at the Georgia Tech site. An example of the types of regression obtained is shown in Figure 3. As can be seen in the figure there is considerable scatter about the one-to-one regression line (not drawn). The regression coefficients in the Tarpley model were

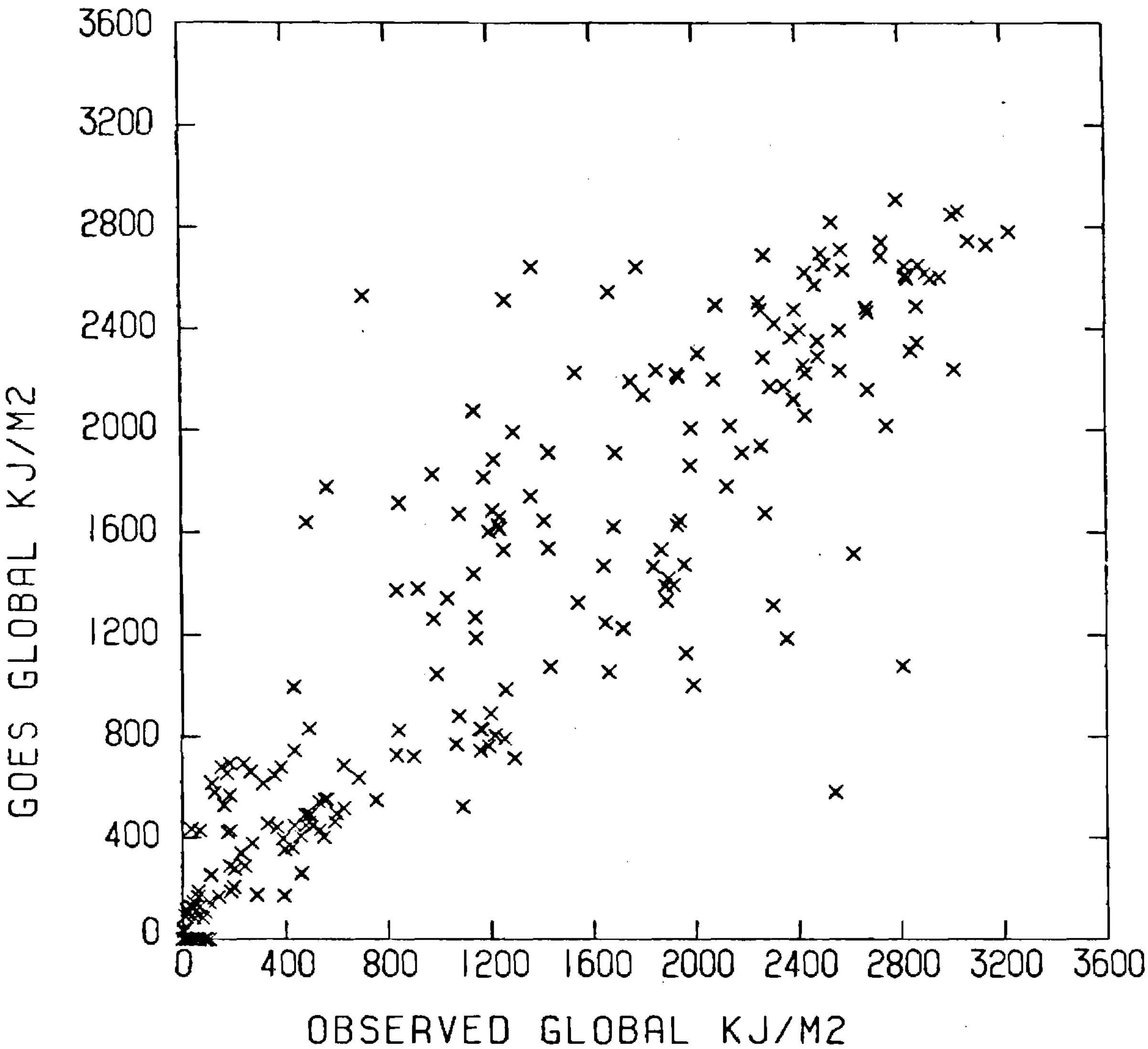

Figure 3. Global radiation derived from GOES satellite brightness data using Tarpley (1980) regression model vs. global radiation measured at Georgia Tech for September 1980.

derived from data taken in the midwest region only. As part of the proposed research we would like to develop regression coefficients from data obtained in our area. Furthermore, we would like to apply a simple physical model like that developed by Gautier, Diak, and Masse (1980). Comparisons between the different models which use satellite data will be made along with comparisons with existing models which use ground based measurements. One such model is the widely used SOLMET regression model. An application of this model on data obtained at the Georgia Tech site yielded the results shown in Figure 4. This regression is somewhat better than that obtained from the Tarpley regression (see Figure 3); but there is still quite a bit of scatter in the plot. Regression coefficients for the SOLMET model were those obtained at Nashville, Tennessee, a locale in the southeast. The results from a second model which uses ground based data is shown in Figure 5. This model is a simple physical multi-cloud layer model which includes the effects of turbidity, water vapor, and clouds. The model shows some improvement over the regression models and has the advantage of not being station or location dependent. Furthermore, it offers the additional advantage of being able to resolve the diffuse and direct components which the regression models cannot do. We feel that these results can be improved with better specification of the attenuation effects of the atmosphere. Most simple models use a broad band attenuation coefficient which applies over the entire solar spectrum. It is well documented that almost all of the attenuation coefficients are wavelength dependent. The use of a single coefficient for the full spectrum certainly leads to error in the cases of aerosol attenuation and water vapor absorption. We are attempting to develop a broad band model which takes into account most of the important features of the wavelength

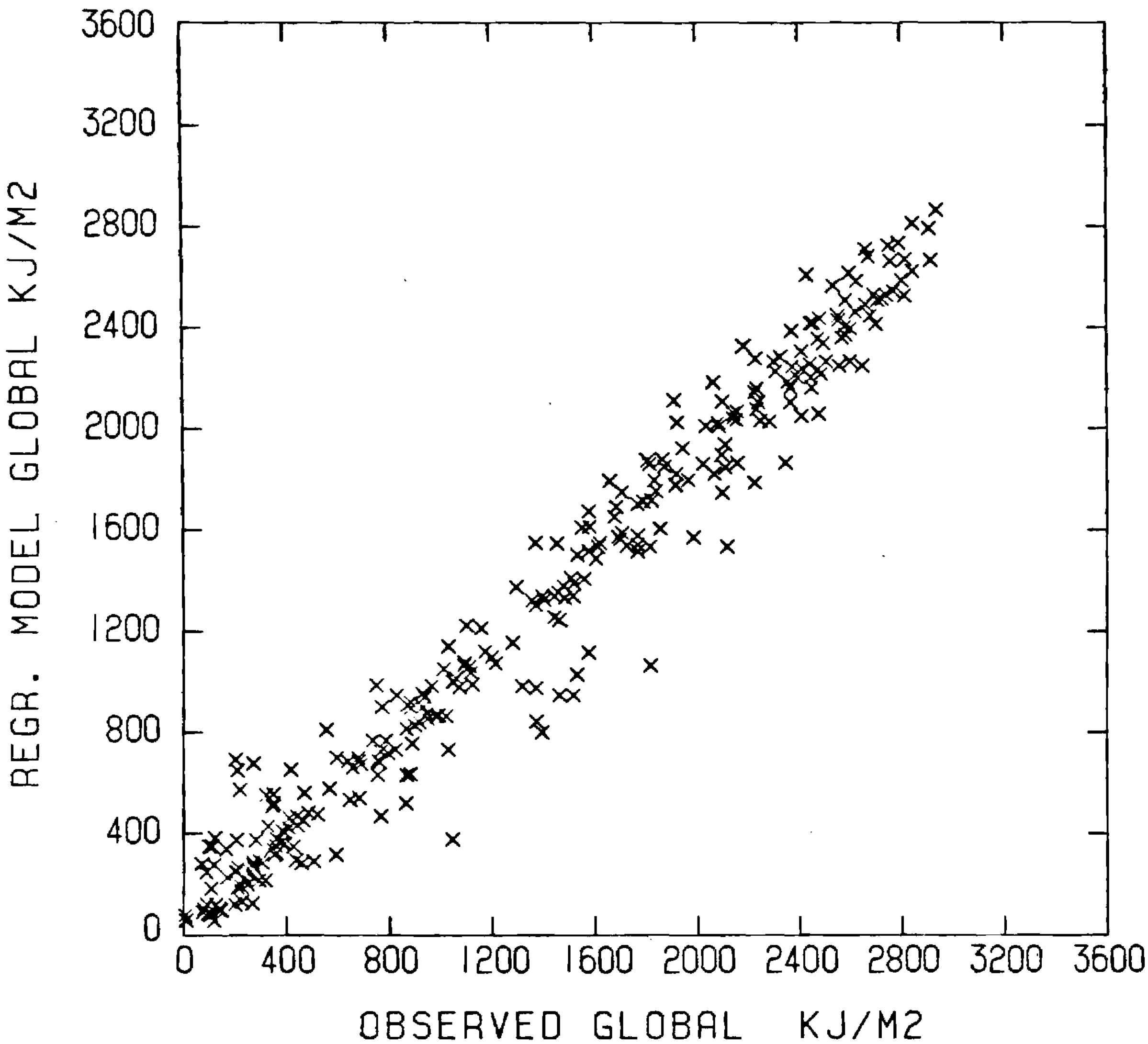

Figure 4. SOLMET regression model global radiation vs. observed global radiation for October 1979.

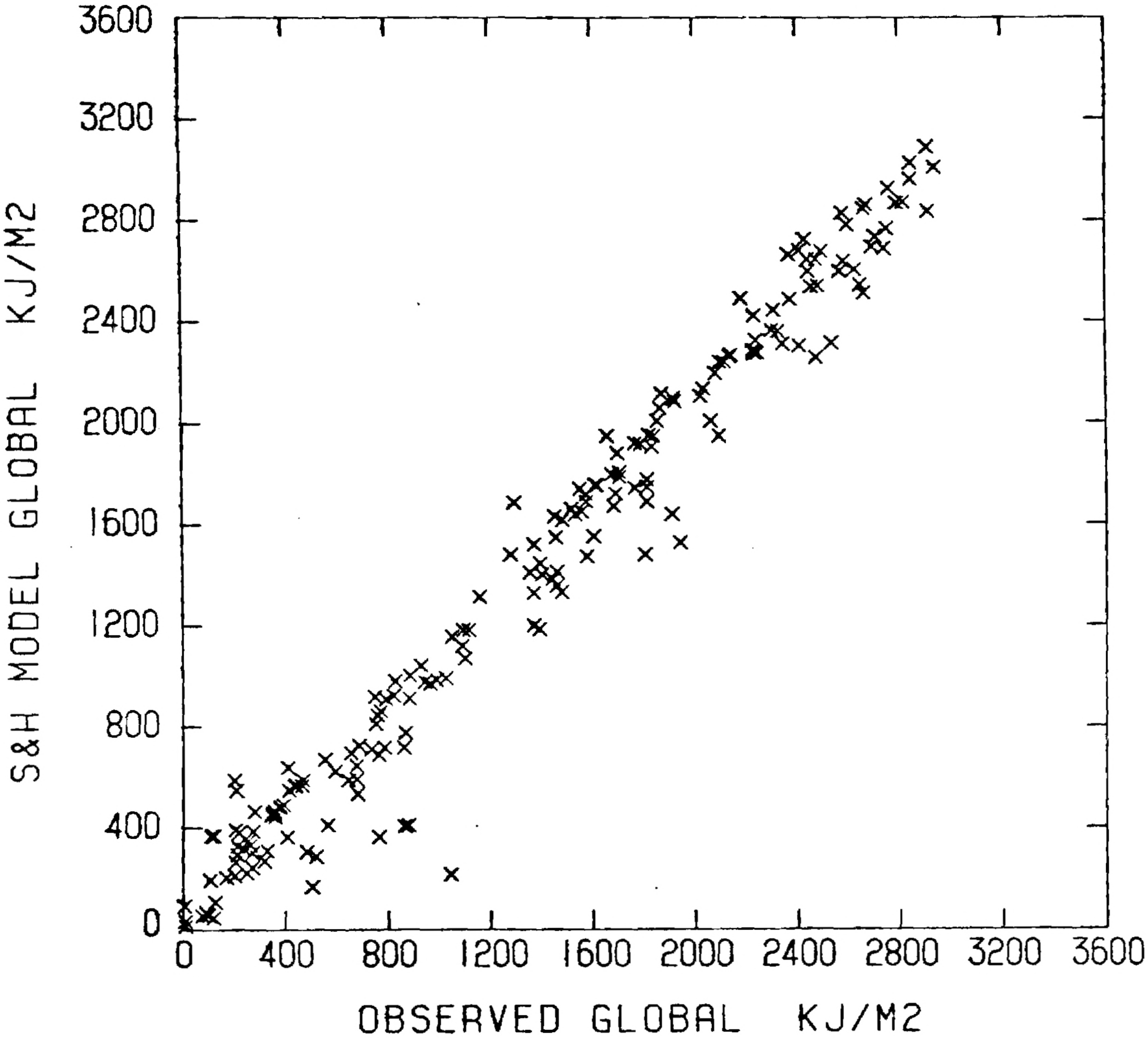

Figure 5. Global radiation derived from a physical model developed at Georgia Tech vs. observed global radiation for October 1979.

dependent attenuation coefficients. High resolution data on line spectra used in rigorous radiative transfer models and elsewhere will be resolved to small band widths and utilized to obtain the broad band attentuation coefficients.

Satellites seem promising in evaluation clouds effects on radiation. Clouds are the dominant atmosphere effect on radiation. Yet, methods for parameterizing clouds in solar energy and climate related radiation models are less well developed than other aspects, such as aerosol induced turbidity in clear skies. As shown by Figures 6-9, models can simulate clear sky conditions much more successfully than cases in which cloud effects dominate. In some cases, however, clear sky effects perhaps caused by time varying turbidity can cause significant "kinks" in the measured data (see Figures 6 and 8, left curves) which are not explained in models which use simple parameterizations such as a fixed turbidity. Also, the models can reproduce the observed direct beam radiation better than they can simulate the global or total (because of inadequate models for the contribution of diffuse sky radiation to the global). Under cloudy conditions, the global radiation received at the surface is composed almost entirely of the diffuse component. During daylight hours, radiation at the surface is at a minimum under cloudy skies. On the other hand, radiation received at the satellite is at a maximum under such conditions. Hence, a combination of ground based observations along with satellite data would offer several advantages: (1) ground truths meausrements for satellite calibration under clear skies when the surface radiation may be well determined, (2) improvement in modeled surface radiation under cloud conditions when the satellite data is most reliable and cloud parameters can be better estimated, (3) evaluation of

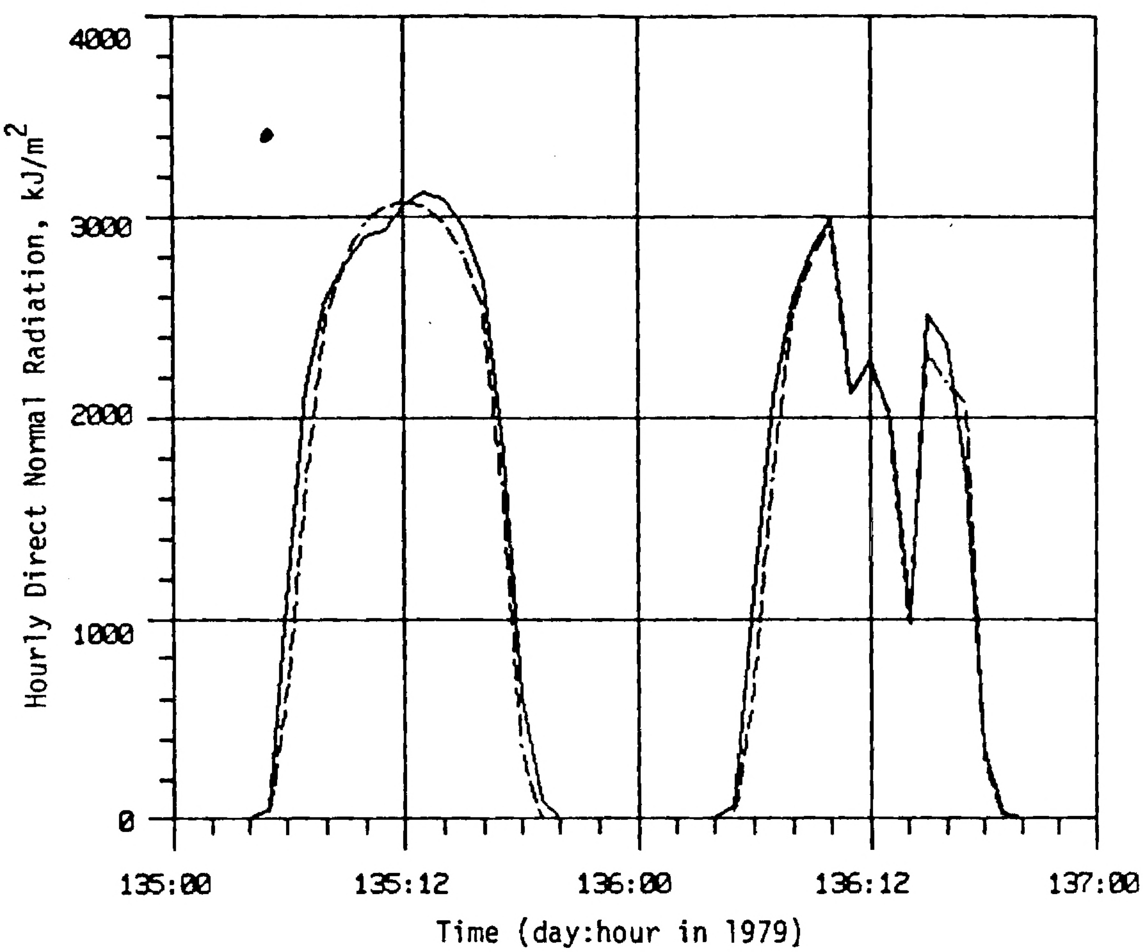

Figure 6. Measured (solid line) versus modeled (dashed line) direct normal radiation for a clear day (135) and a partly cloudy day (136) in 1979.

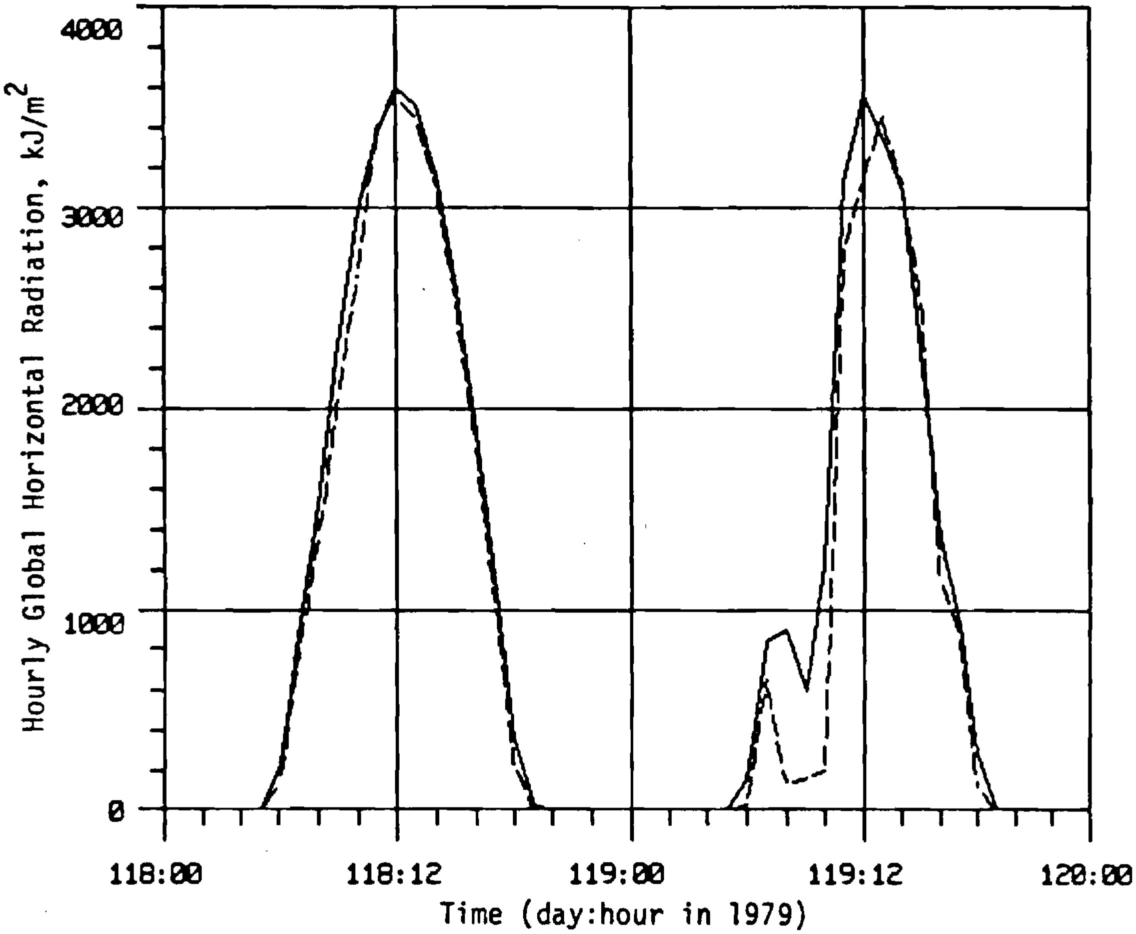

Figure 7. Measured (solid line) versus modeled (dashed line) global radiation for a clear day (135) and a partly cloudy day (136) in 1979.

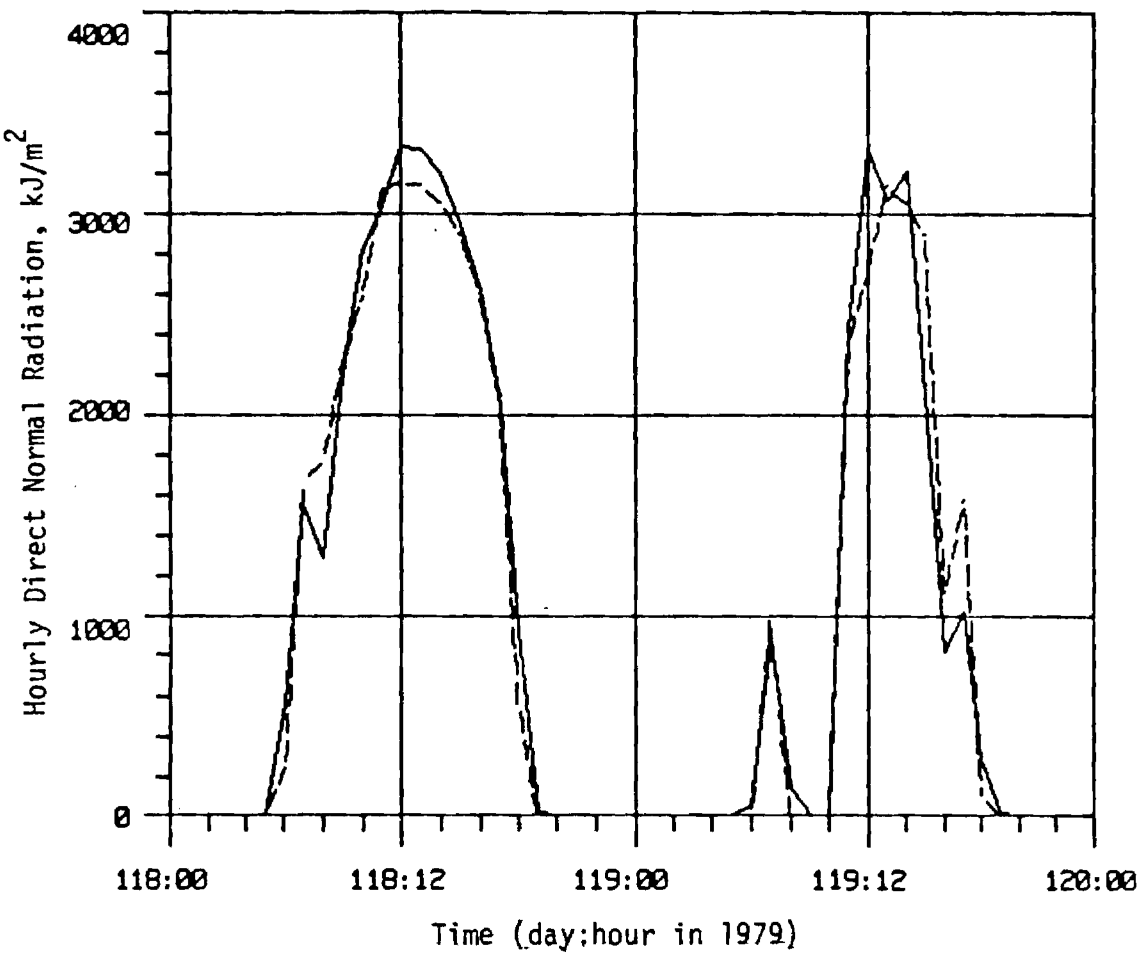

Figure 8. As in Figure 1 for days 118 (clear) and 119 (partly cloudy).

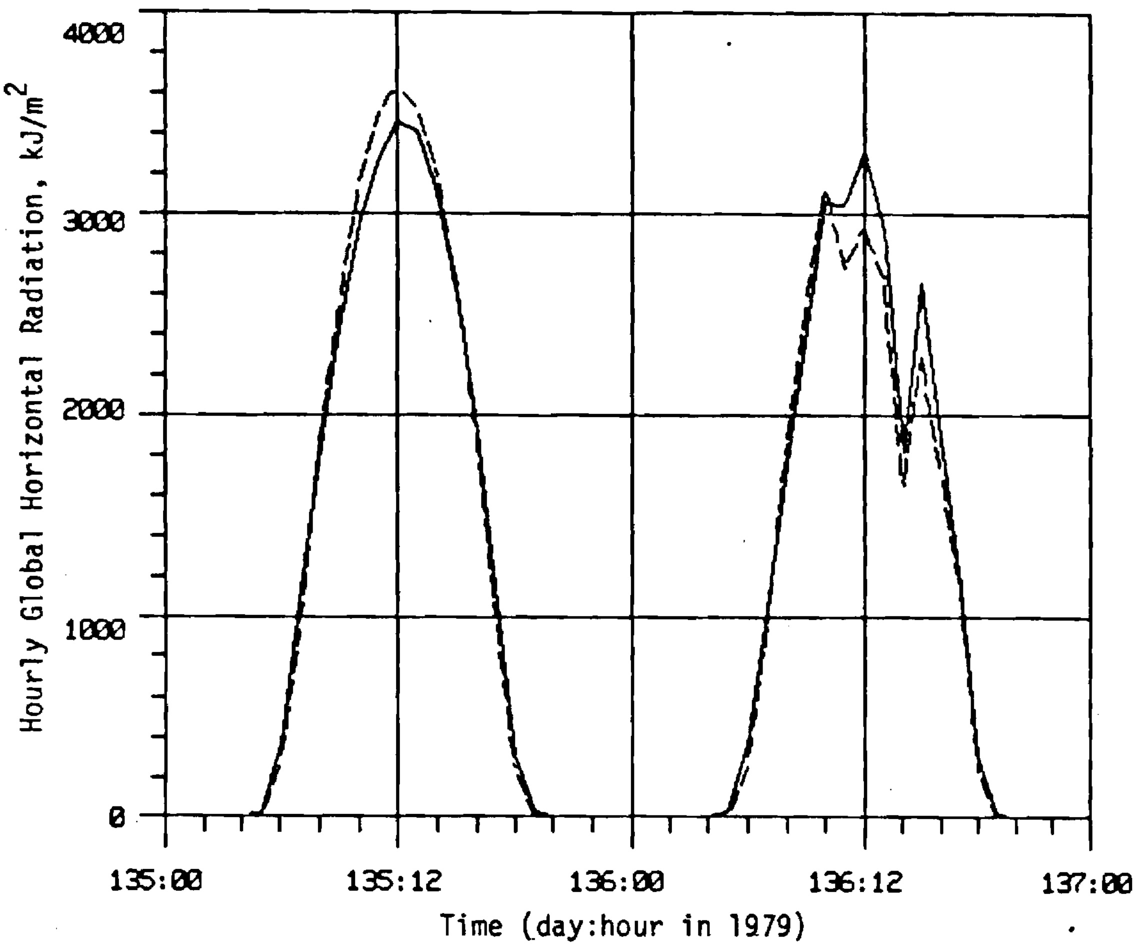

Figure 9. As in Figure 2 for days 118 (clear) and 119 (partly cloudy).

turbidity effects both from ground based observations and satellite derived values (differences in brightness observed over the same area on different clear days can be attributed to changes in turbidity), (4) correlations of NWS reported cloud cover with satellite derived values. Satellite data also offer some estimation of the depth of clouds, and (5) regional and even global coverage on a continuous basis. We believe that such a combination shows significant promise in arriving at a much improved assessment of the solar resource.

Data derived from the SBUV/TOMS, SAM, and SAGE sensors on NASA's Nimbus satellites will provide much needed information on ozone, aerosols, and water vapor in the earth's atmosphere on a global scale. These data will be used in Dr. Lewis' radiative transfer studies. Hence, we believe that the development of Dr. Lewis' expertise in satellite data measurement and analysis will aid our research efforts greatly as well as provide significant career development for the applicant.

II. Project Objectives and Progress

The proposed research was composed of four main objectives or tasks. They were:

1. Solar radiation data measurements, interpretation, and modeling;

2. Collaboration with NOAA and other national laboratories;

3. Interaction with regional colleges; and

4. Development of expertise and experience in the use of satellite data.

The progress made under each of these objectives is discussed in the following subsections.

Task 1: Solar Radiation Data Measurements, Interpretations, and Modeling

MEASUREMENTS

Measurements at the Southeast regional DOE Solar Energy Meteorological Research ant Training Site (SEMRTS) located at Georgia Tech have continued despite severe setbacks in funding from DOE. The site continuously monitors and records global, direct, diffuse, global tilted, UV, IR, and other spectral radiation parameters. The measurements being taken and instruments used are listed in Table I. The hourly data bases have been updated to include cloud observations reported by the National Weather Service (NWS) as well as some data derived from a locally operated all-sky camera. Precipitable water amounts have also been merged into the data bases. In addition, automatic turbidity measurements in the 0.5 μm bandpass have been added to the data bases. All of these measurements have been used in modeling studies and in interpreting the solar radiation data collected.

INTERPRETATION

Turbidity and Precipitable Water Effects on Direct Beam

Measurements of atmospheric turbidity at a wavelength of 500 nm have been made both with a hand-held Volz photometer and an automatic-tracking sunphotometer designed at Georgia Tech. The 500 nm turbidity is defined as

$$\tau_{500} = [\ell n \; (I(500)/I_o(500) + \tau_R + \tau_o) \; M(p/p_o)]/M \qquad (1)$$

where I(500) is the observed 500 nm relative intensity, $I_o(500)$ is the air mass-zero 500 nm relative intensity (extrapolated from a "Langley plot" for the instrument being used), τ_R and τ_o are Rayleigh and ozone turbidity factors ($\tau_R+\tau_o$ = 0.155

TABLE 1

ATLANTA, GEORGIA TECH SITE
(C.E. BUILDING ROOF ON GA. TECH CAMPUS)
RESEARCH COOPERATOR DATA DESCRIPTION

Latitude = 33° 46' 37" N
Longitude = 84° 23' 54" W
Time Zone = Eastern (5)

	Elevation		Orientation		Spectral Band μ			
Element Code	MSL, m	AGL, m	Azimuth	Tilt	Lower	Upper	Description	Units
1000	326.8	34.8	0	0	0.29	2.80	Global Horizontal, Eppley PSP	kJ/m^2
1001	326.8	34.8	0	0	0.29	2.80	Global Horizontal, Spectrolab SR 75	kJ/m^2
1002 (1)	326.8	34.8	0	0	0.38	1.20	Global Horizontal, LiCor Lambda	kJ/m^2
1003	326.8	34.8	0	0	0.38	1.20	Global Horizontal, Dodge Products Solar Cell	kJ/m^2
1460	326.8	34.8	180	34	0.29	2.80	Global Latitude Tilted, PSP w/artificial horizon	kJ/m^2
1461 (2)	326.8	34.8	180	34	0.29	2.80	Global Latitude Tilted, Lambda w/artificial horizon	kJ/m^2
2010	326.8	34.8	-	-	0.29	2.80	Direct Normal, Eppley NIP	kJ/m^2
2011 (2)	326.8	34.8	-	-	0.29	2.80	Direct Normal, Eppley NIP (redundant)	kJ/m^2
2012	326.8	34.8	-	-	0.38	1.20	Direct Normal, LiCor Lambda w/colimator	kJ/m^2
3000 (3)	326.8	34.8	0	0	0.29	2.80	Diffuse, PSP and tracking disk	kJ/m^2
3001	326.8	34.8	0	0	0.29	2.80	Diffuse, PSP and tracking disk	kJ/m^2
5000	326.8	34.8	0	0	0.30	0.39	UV, Eppley TUVR	kJ/m^2
6000 (4)	326.8	34.8	0	0	2.80	60.0	IR from Total Incoming (Funk) minus Global (PSP)	kJ/m^2
6001	326.8	34.8	0	0	3.5	50.0	IR from Eppley PIR	kJ/m^2
7000	326.8	34.8	0	0	0.63	2.80	Global Spectral, PSP and RG2 filter	kJ/m^2
7010	326.8	34.8	0	0	0.63	2.80	Direct Normal Spectral, NIP and RG2 filter	kJ/m^2
9000 (5)	326.8	34.8	-	-	-	-	% Possible Sunshine, Campbell Stokes	%
9001 (5)	326.8	34.8	-	-	-	-	% Possible Sunshine, NIP w/200 W/m^2 threshold	%
9150 (6)	326.8	34.8	-	-	-	-	Rainfall	mm
9200	332.9	40.9	-	-	-	-	Wind Direction, lower level	deg
9201	343.3	51.3	-	-	-	-	Wind Direction, upper level	deg
9210	332.9	40.9	-	-	-	-	Wind Speed, lower level	m/s
9211	343.3	51.3	-	-	-	-	Wind Speed, upper level	m/s
9300	329.8	37.8	-	-	-	-	Dry Bulb Temperature, lower level	°C
9301	343.0	51.0	-	-	-	-	Dry Bulb Temperature, upper level	°C
9320	329.8	37.8	-	-	-	-	Dew Point Temperature, lower level	°C
9321	343.0	51.0	-	-	-	-	Dew Point Temperature, upper level	°C
9400	326.8	34.8	-	-	-	-	Station Pressure	kPa

(1) Not available after 10/26/79; (2) Available after 2/1/80; (3) Available after 1/10/80; (4) Available after 4/14/80;
(5) Available only in hourly RCF; (6) Minute rainfall is cumulative from beginning of hour.

for the sensors used) and M is relative air mass (secant zenith angle for zenith angles less than about 80°).

Figures 10 and 11 show the observed variation of direct/extraterrestrial radiation versus turbidity, measured by the automatic sensor, or precipitable water, determined from Athens, GA upper-air balloon soundings. Both of these figures are for clear sky conditions only (% sunshine = 100, opaque cloud = 0) and for air masses less than 2.

The direct/extraterrestrial ratio (N/N_0) can be used to define a broad-band turbidity (τ) by the relation

$$\tau = - \ln(N/N_0)/M \tag{2}$$

[note that Rayleigh, ozone, or other effects are not explicitly removed from the calculations of the broad-band turbidity as they are for the 500 nm turbidity in equation (1)].

Figures 12 and 13 show plots of τ versus τ_{500} as determined from the Volz photometer (Figure 12) or the Georgia Tech automated sunphotometer (Figure 13). In Figure 12, the best-fit linear regression is

$$\tau = 0.26 + 0.533\ \tau_{500}\ \text{(Volz)} \tag{3}$$

with an rms error of regression of 0.036 in τ. Figure 13 yields

$$\tau = 0.19 + 0.362\ \tau_{500}\ \text{(auto)} \tag{4}$$

with an rms error of 0.022.

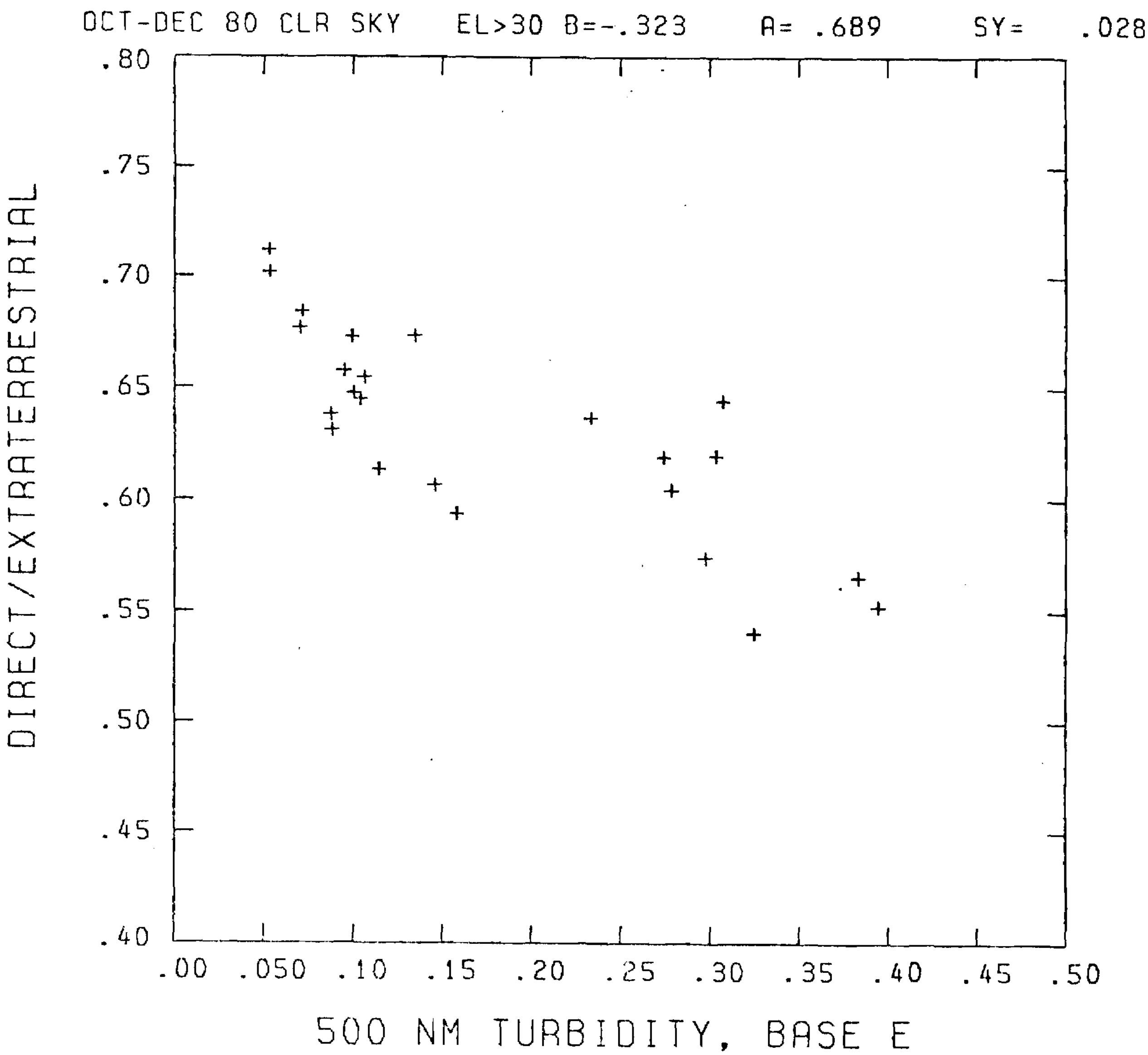

Fig. 10. Direct Extraterrestrial (N/N_0) versus turbidity (τ_{500}) from automatic sensor for relative air masses < 2. October-December 1980, clear skies only.

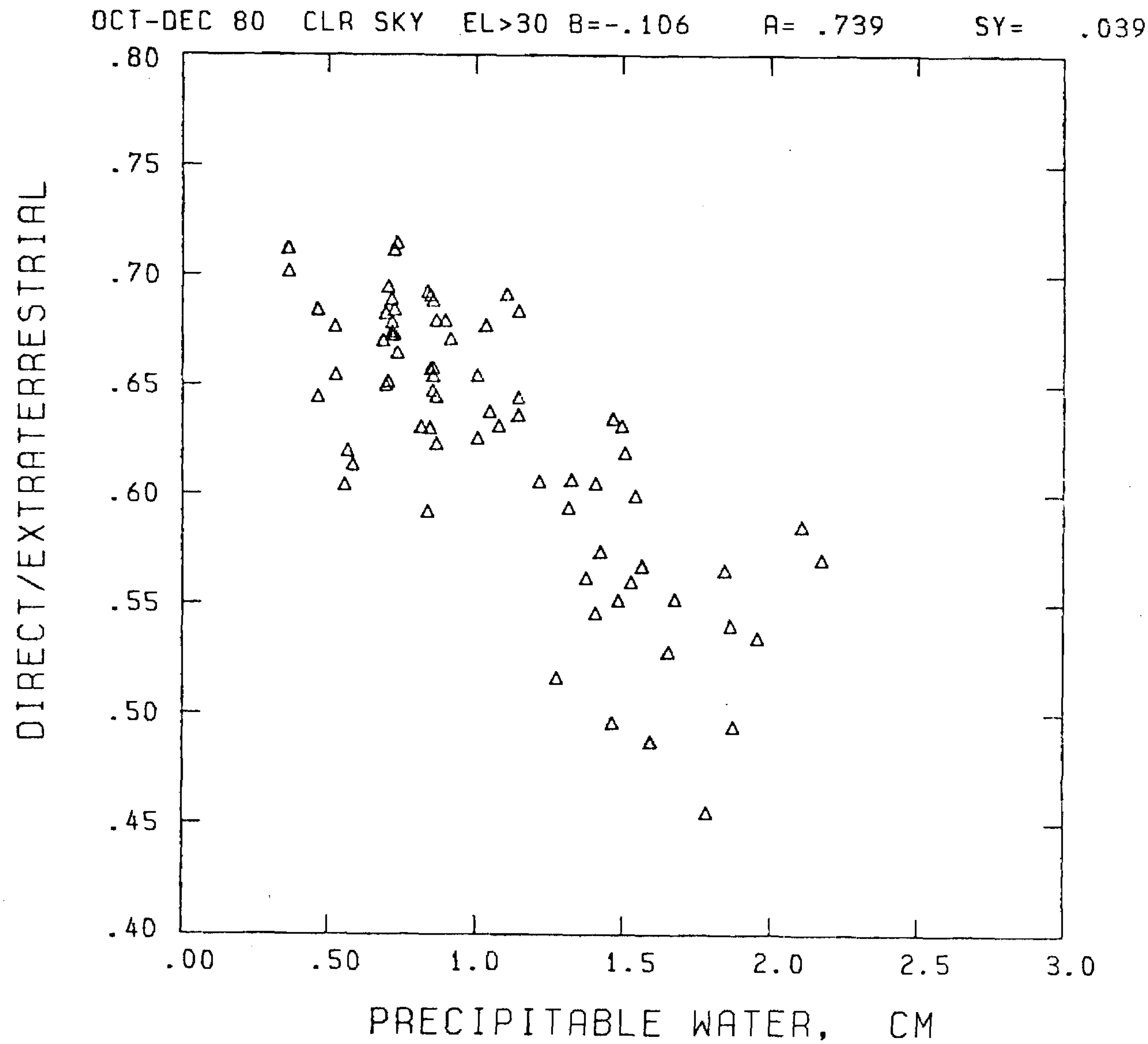

Fig. 11. Direct/Extraterrestrial (N/N_0) versus precipitable water for October-December 1980, clear sky conditions.

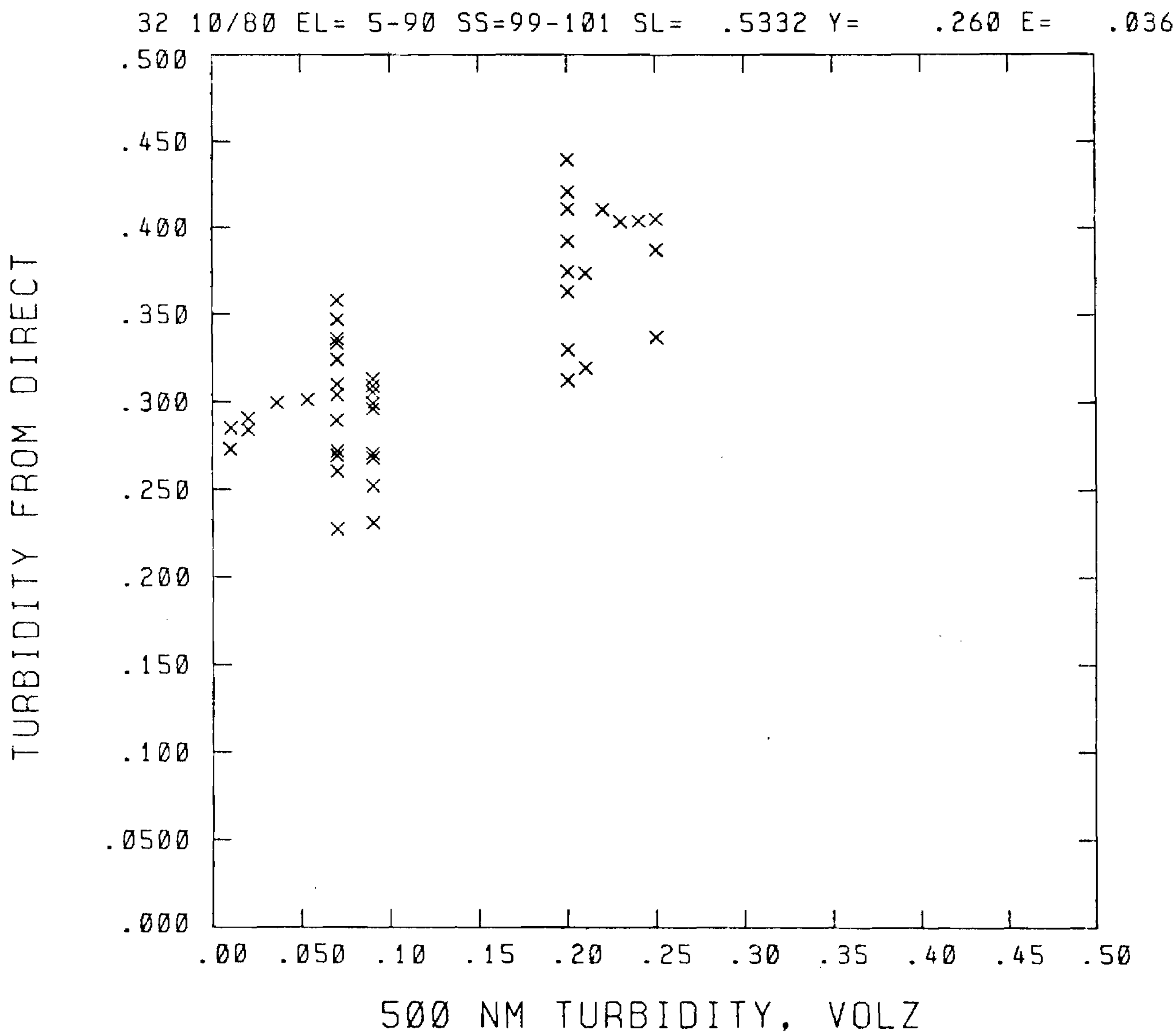

Fig. 12. Broad-band turbidity (τ) versus 500 nm turbidity (τ_{500}) from the Volz photometer.

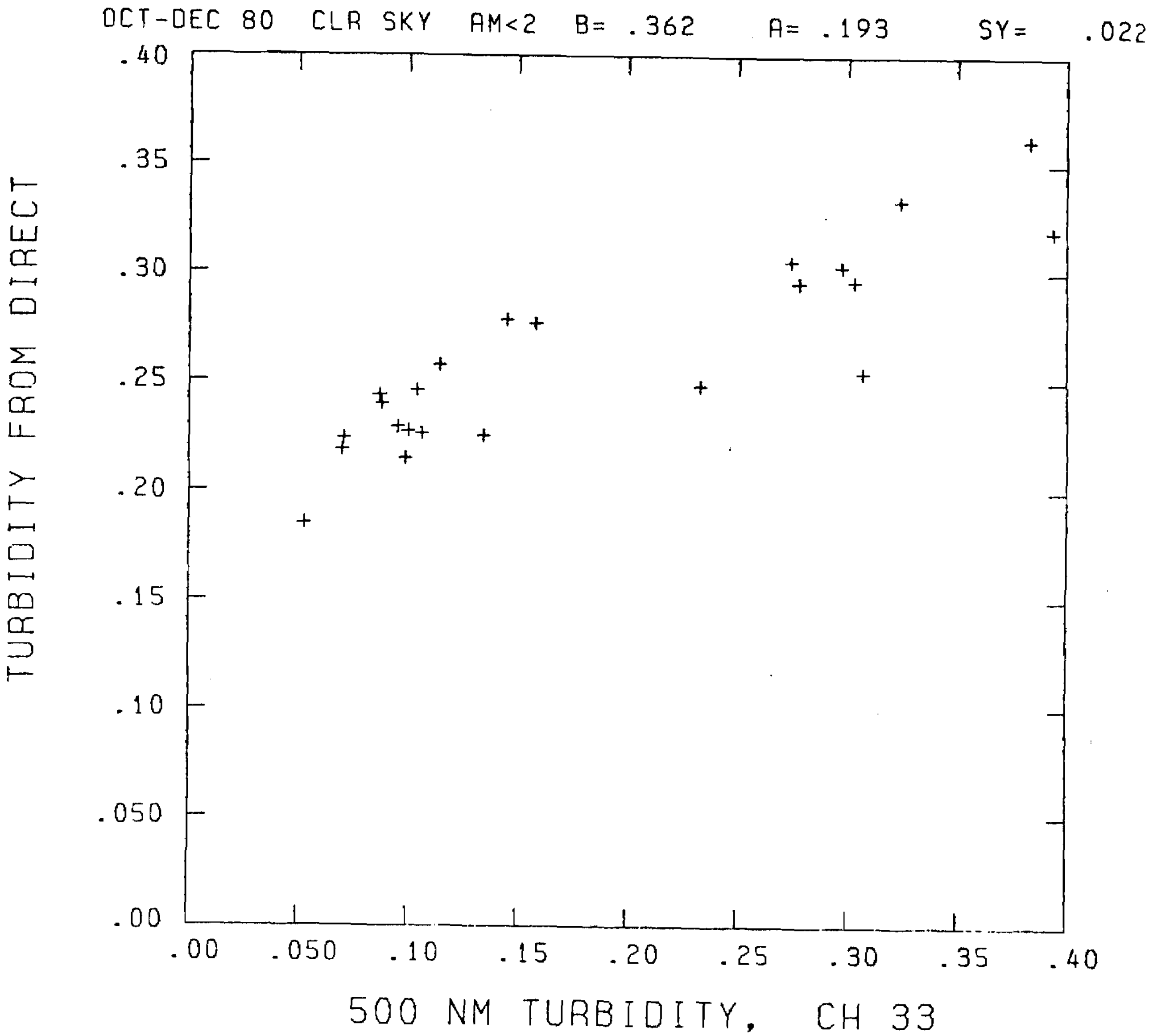

Fig. 13. Broad-band turbidity (τ) versus 500 nm turbidity (τ_{500}) from the Georgia Tech automated sunphotometer.

A better correspondence is found between the ratio diffuse/direct radiation and broad-band turbidity, as shown in Figure 14, which indicates

$$\tau = 0.16 + 1.35\ (D/N) \qquad (5)$$

where D is the diffuse (all-sky) radiation on a horizontal surface and N is the direct normal radiation. The regression (5) has an rms error of only 0.019. Dependence of the diffuse/direct ratio on τ_{500} is illustrated in Figure 15.

The effect of turbidity and precipitable water on the direct beam, is illustrated in Figure 10 and 11, are not entirely independent. Figure 16 indicates that the 500 nm turbidity has a distinct direct trend with precipitable water, with a "best-fit" regression of

$$\tau_{500} = 0.02 + 0.169\ (PW) \qquad (6)$$

with an rms regression error of 0.08 in τ_{500}. PW is prcipitable water in cm.

Effects of Turbidity and Precipitable Water on Spectral Ratio

As shown in Figures 12 and 13 (from Chapter 16 of the 1965 AFCRL Handbook of Geophysical and Space Environment), essentially all of the water vapor absorption occurs at wavelengths above 0.63 μ (630 nm). Thus, the direct spectral radiation N(>630) measured through a 630 μm filter

$$N(>630) = \int_{630}^{\infty} N(\lambda)d\lambda \qquad (7)$$

should be a measure of precipitable water attenuation effects. The direct beam also reddens with increasing air mass, i.e., N(>630)/N gets larger. Hence, it seems reasonable that N(>630)/N should show an opposite effect (i.e., decrease)

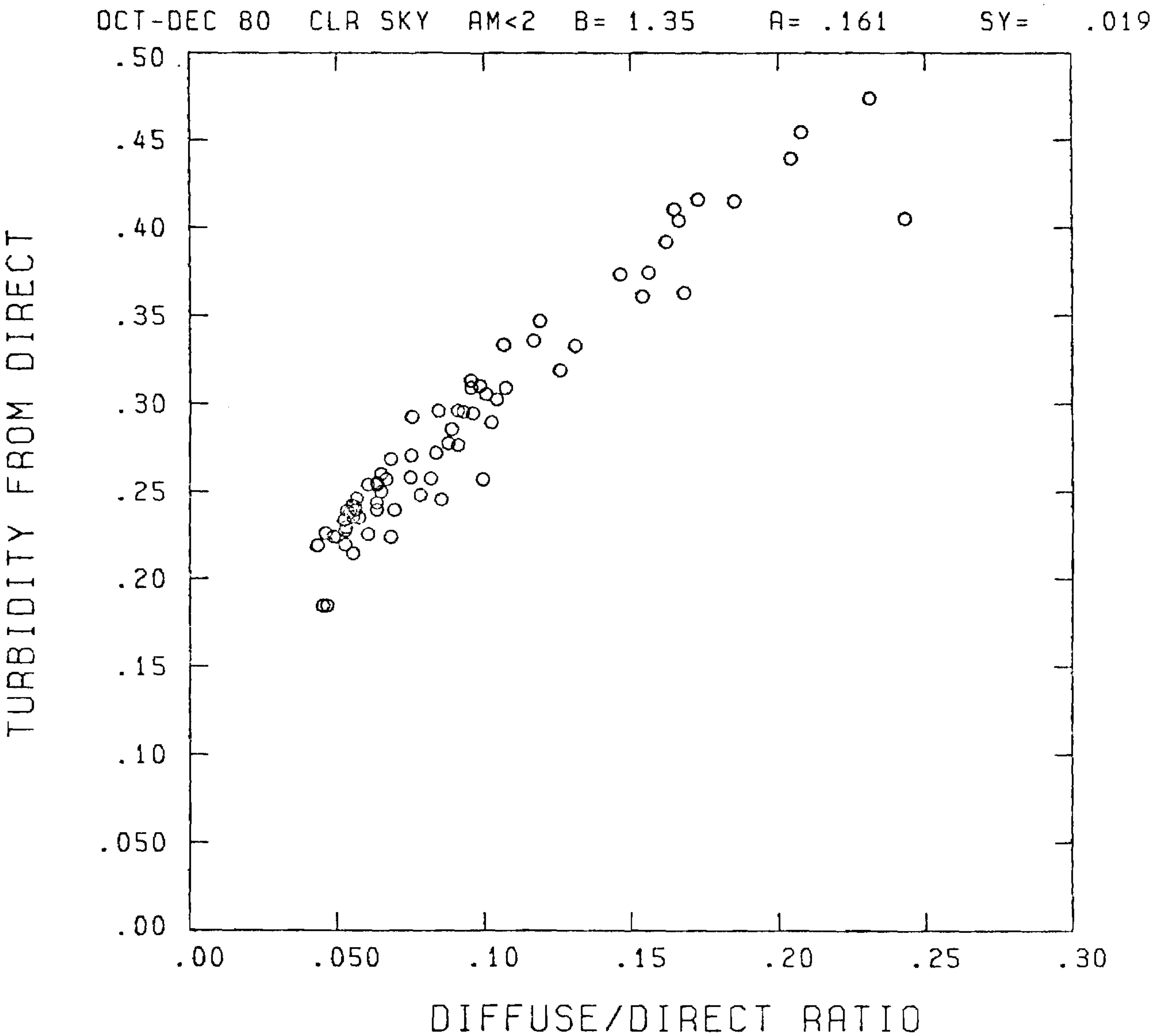

Fig. 14. Broad-band turbidity (τ) versus ratio/diffuse direct.

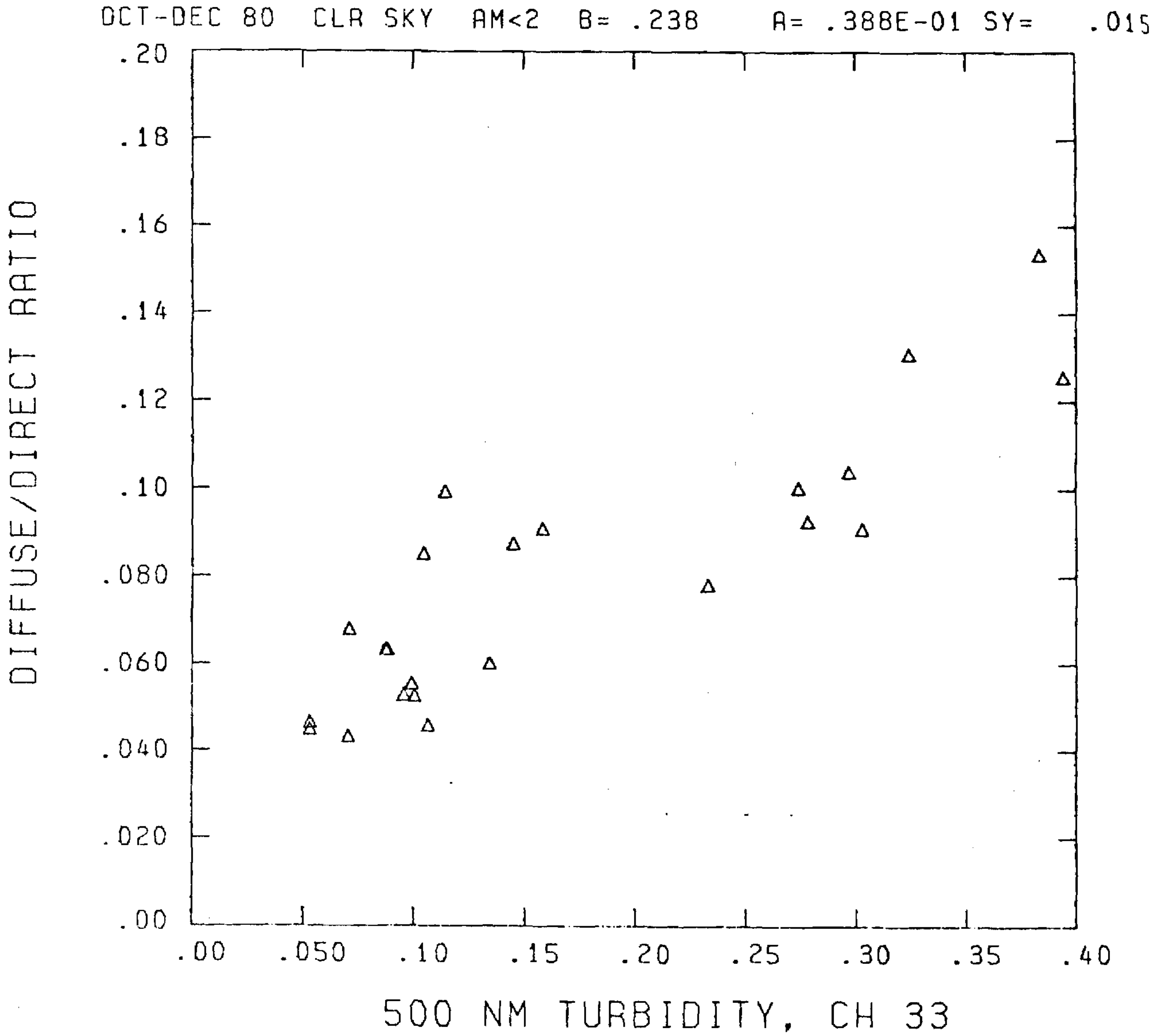

Fig. 15. Diffuse/direct ratio versus 500 nm turbidity from the automated sensor.

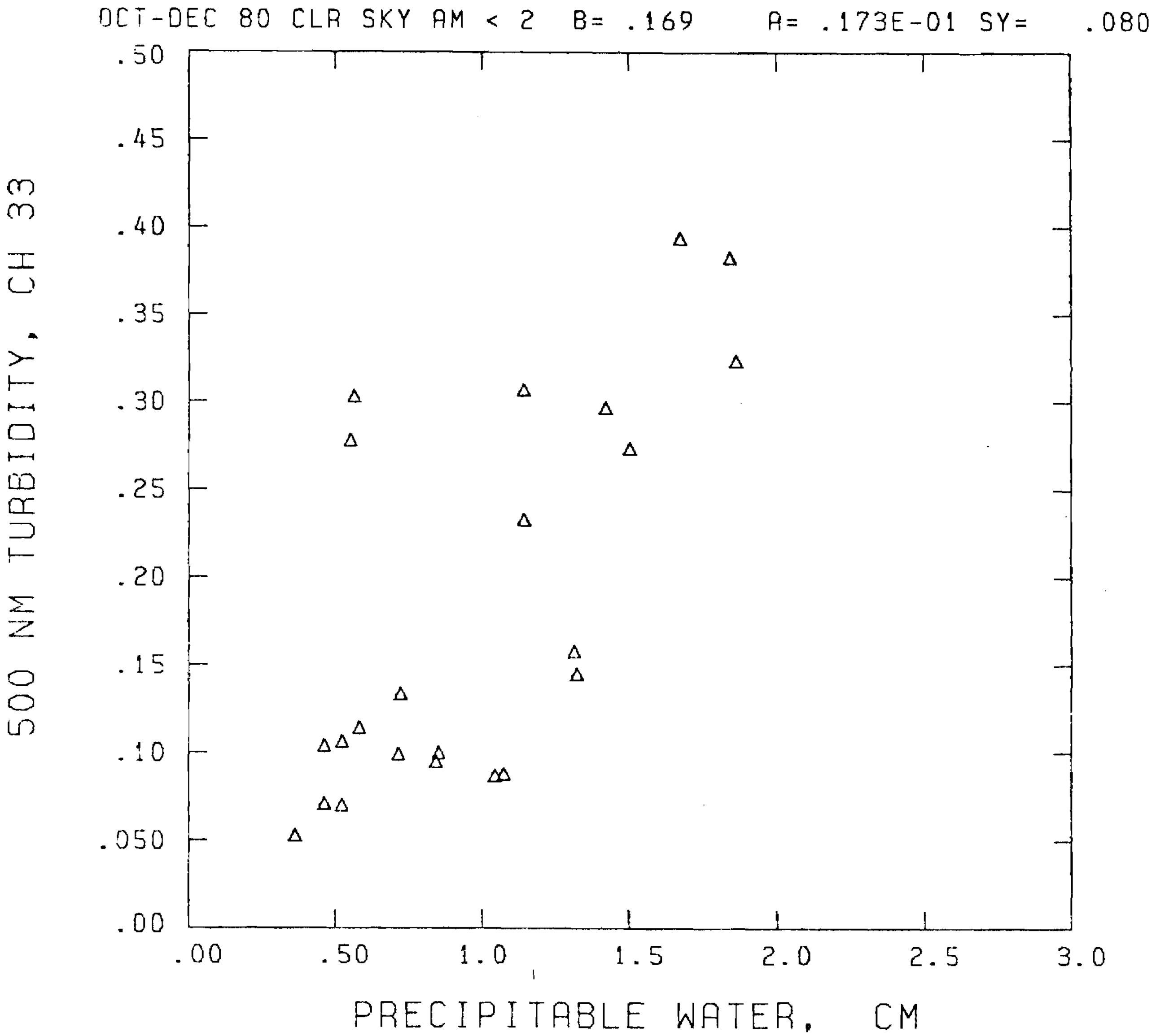

Fig. 16. 500 nm turbidity versus precipitable water.

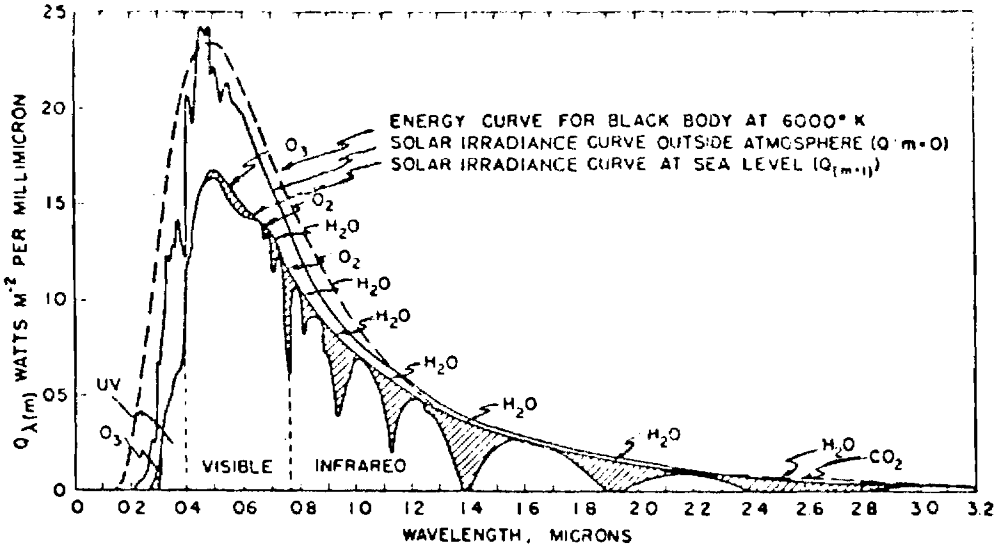

Fig. 17. Solar Spectral Energy Curves showing absorption due to various atmospheric constituents.

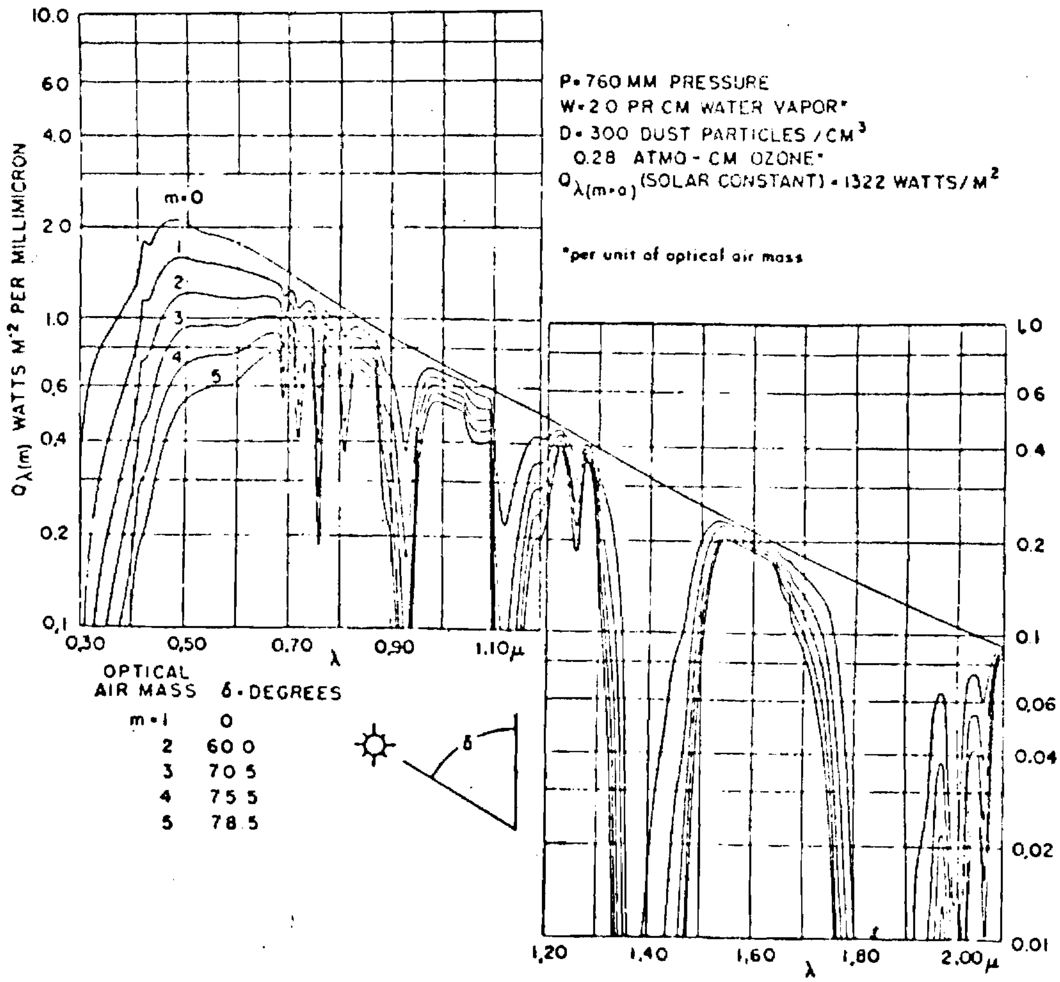

Fig. 18. Solar Spectral Irradiance Curves at Sea Level with Varying Optical Air Masses.

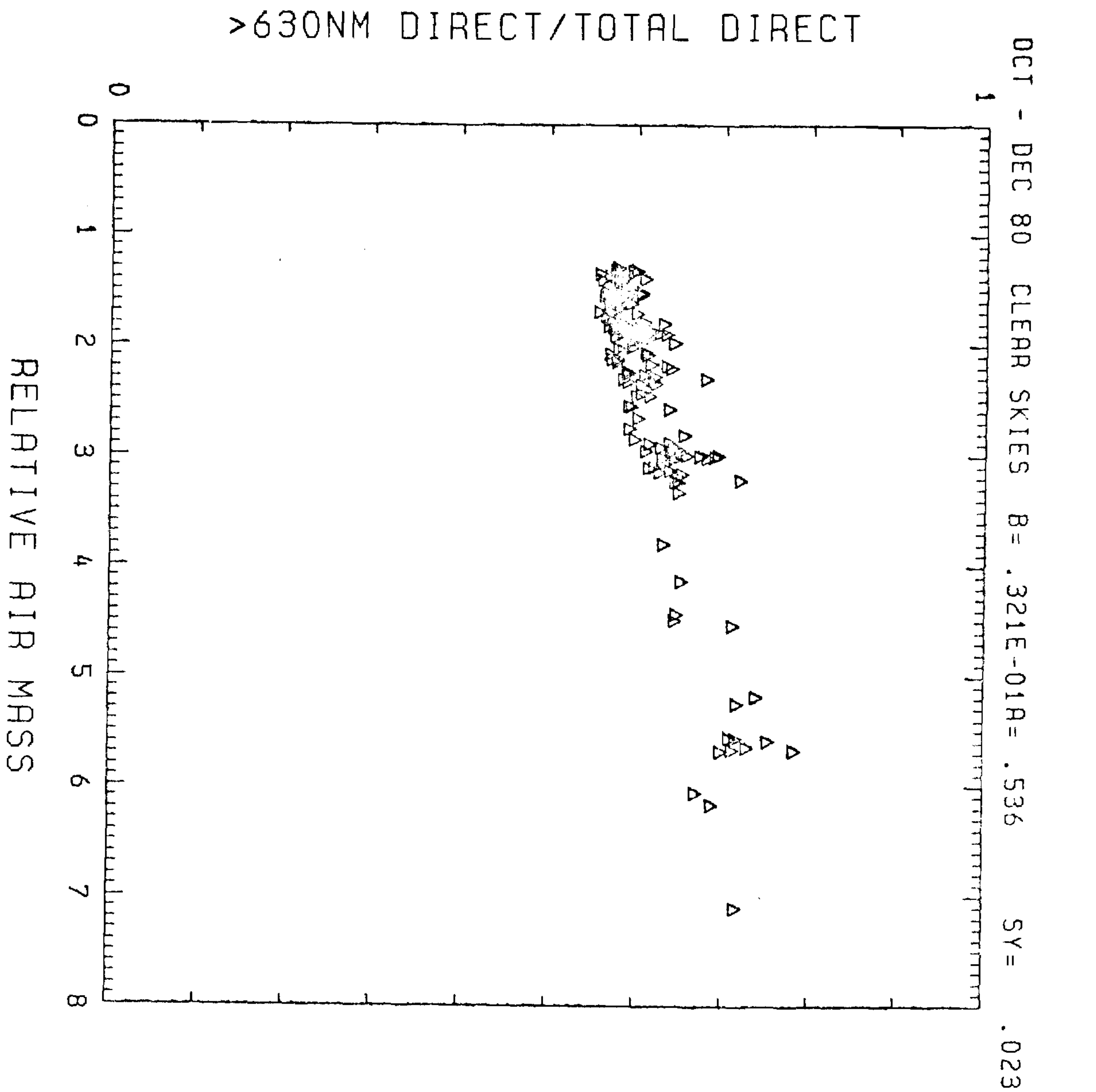

Fig. 19. Direct Beam Spectral ratio of (RG630 Direct)/ (Total Direct) [N (>630 nm)/N] versus air mass. October-December 1980, clear sky conditions.

with increased water vapor at a fixed air mass. Figure 19 shows the expected reddening (increased N(630)/N) with air mass for clear sky conditions (100% sunshine, 0 opaque cloud cover). However, Figure 20 shows no significant effect of N(>630)/N with precipitable water amounts for the limited air mass range M<2 for clear skies. Figure 21 does show a slight (non-significant) downward trend of the spectral ratio with 500 nm turbidity.

MODELING

Modeling efforts concentrated on a radiative transfer code developed by the author while at the State University of New York at Albany (Lewis, 1980). The model uses a modified version of the classical method of successive order of scattering to solve the equation of transfer. This method employs an iterative scheme in which each iteration includes a higher order of scattering. The method has been outlined by Dave and Gazdag (1970) and has been employed by Braslau and Dave (1973). The atmosphere is simulated by a midlatitude standard atmosphere as defined by McClatchey et al. (1972). The solar spectrum between 0.3 μm and 1.3 μm was divided into five wavelength regions of equal widths and a representative wavelength chosen for each spectral region. The spectral fluxes at the top of the atmosphere were taken from Theaekara (1973).

Initial efforts were directed toward making the code which was developed on a Univac 1110 computer compatible first with a Data General Eclipse, then with a CYBER 70/74, and later with a CYBER 70/760 and ultimately with a DECSYSTEM 2060 computer. Other modifications and improvements to the program were initiated including improvement in time resolution, better approximation of the scattering phase function of aerosols through use of a Henyey-Greenstein function employing data analyzed here at Georgia Tech. Further improvements in the model were sought

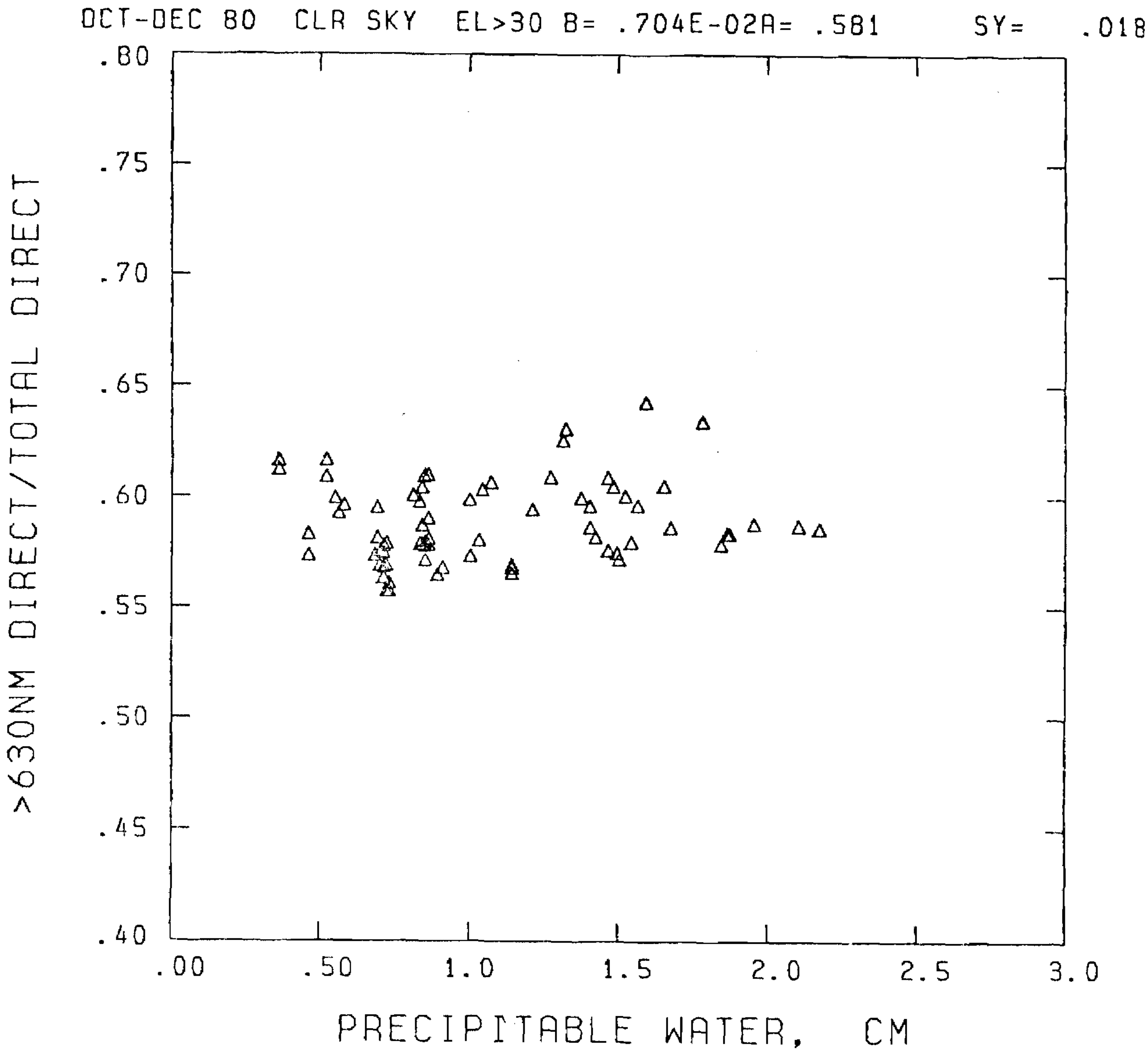

Fig. 20. Direct Beam Spectral Ratio [N (>630 nm)/N] versus precipitable water. Air Masses < 2, clear skies.

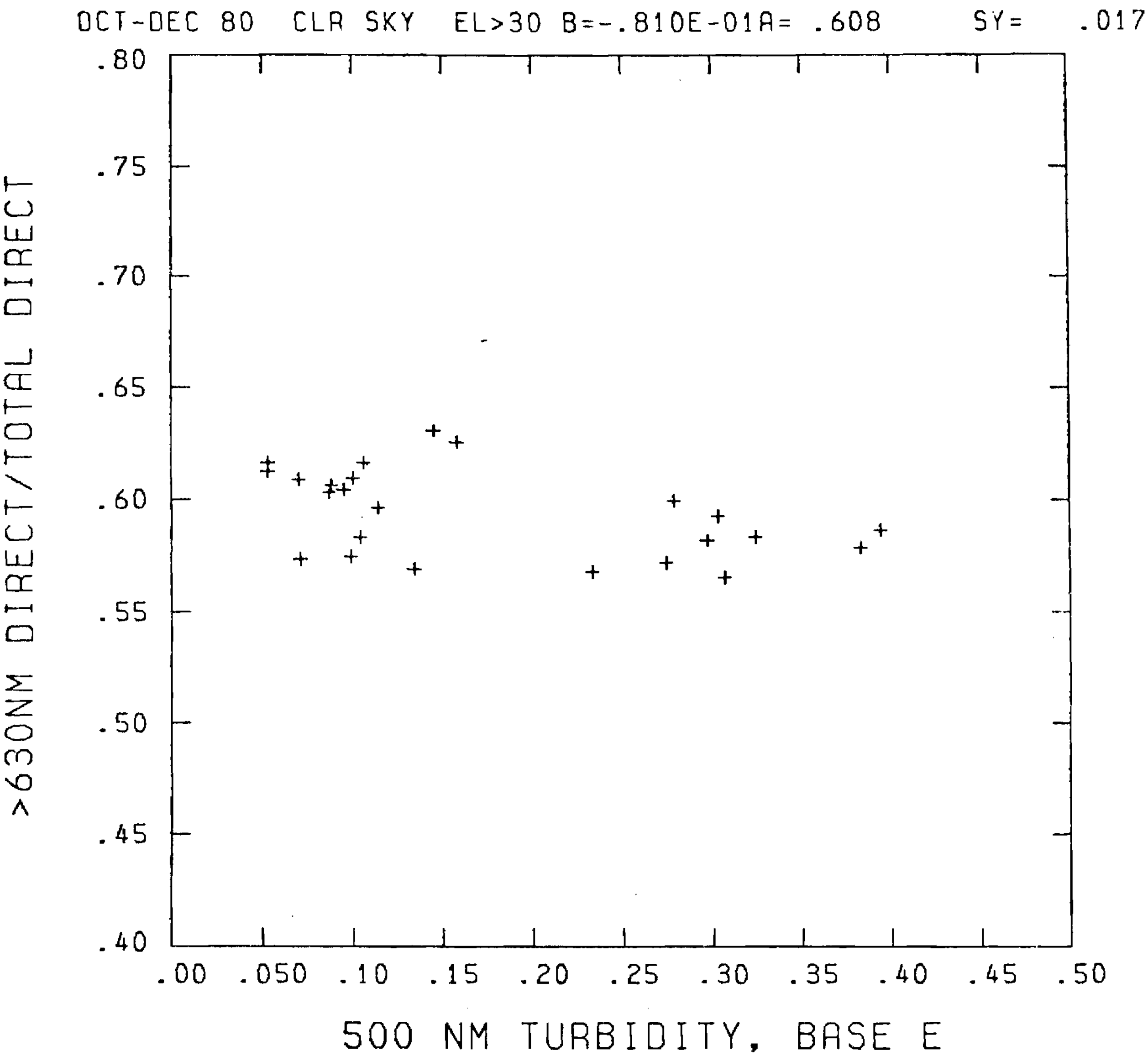

Fig. 21. Direct Beam Spectral Ratio [N (>630 nm)/N] versus 500 nm turbidity. October-December 1980, clear skies, air mass < 2.

by utilizing the cloud data from the NWS network and cloud cover as derived from a modified normal incidence pyrheliometer (NIP) to evaluate the effects of clouds.

The performance of the model proved less than satisfactory. Calculated daily totals on clear days agreed within about 15 percent with the measured values but calcualted hourly totals differed by more than 25 percent from the observed values. The performance was even less satisfactory for cloudy days. Figures 22 - 24 show examples of model output compared with measured values. Much of the discrepancy between modeled value and measured value is probably due to the method used to generate the fluxes. The flux value calculated is an instantaneous value. This instantaneous value is then considered constant for the time period considered and converted to an hourly total. Furthermore, no absorption was considered in the model. Although the model does not show considerable promise of predicting hourly totals, it has potential for developing values for spot comparisons with radiometers.

Other models are now being pursued to generate daily totals. A copy of the radiation code SOLTRAN5 developed by R. Bird and R. Hulstrom of SERI has been obtained. Efforts are underway to make this code compatible with the DECSYSTEM 20 computer and also compatible with our specific objectives. SOLTRAN5 is capable of generating spectral fluxes as well as total insolation.

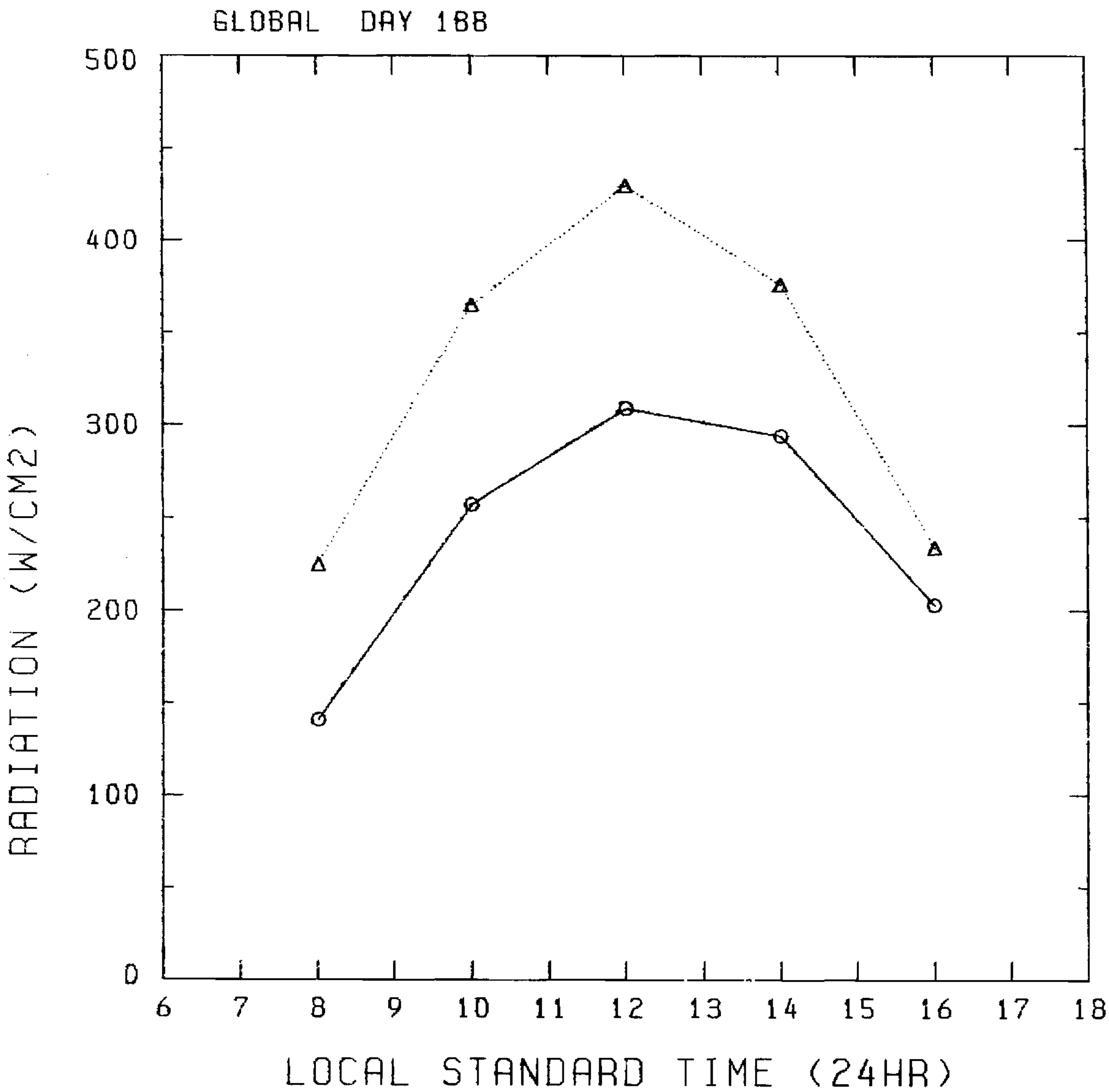

Figure 22. Calculated versus measured Global Radiation on Day 188 (——— measured; ------ calculated).

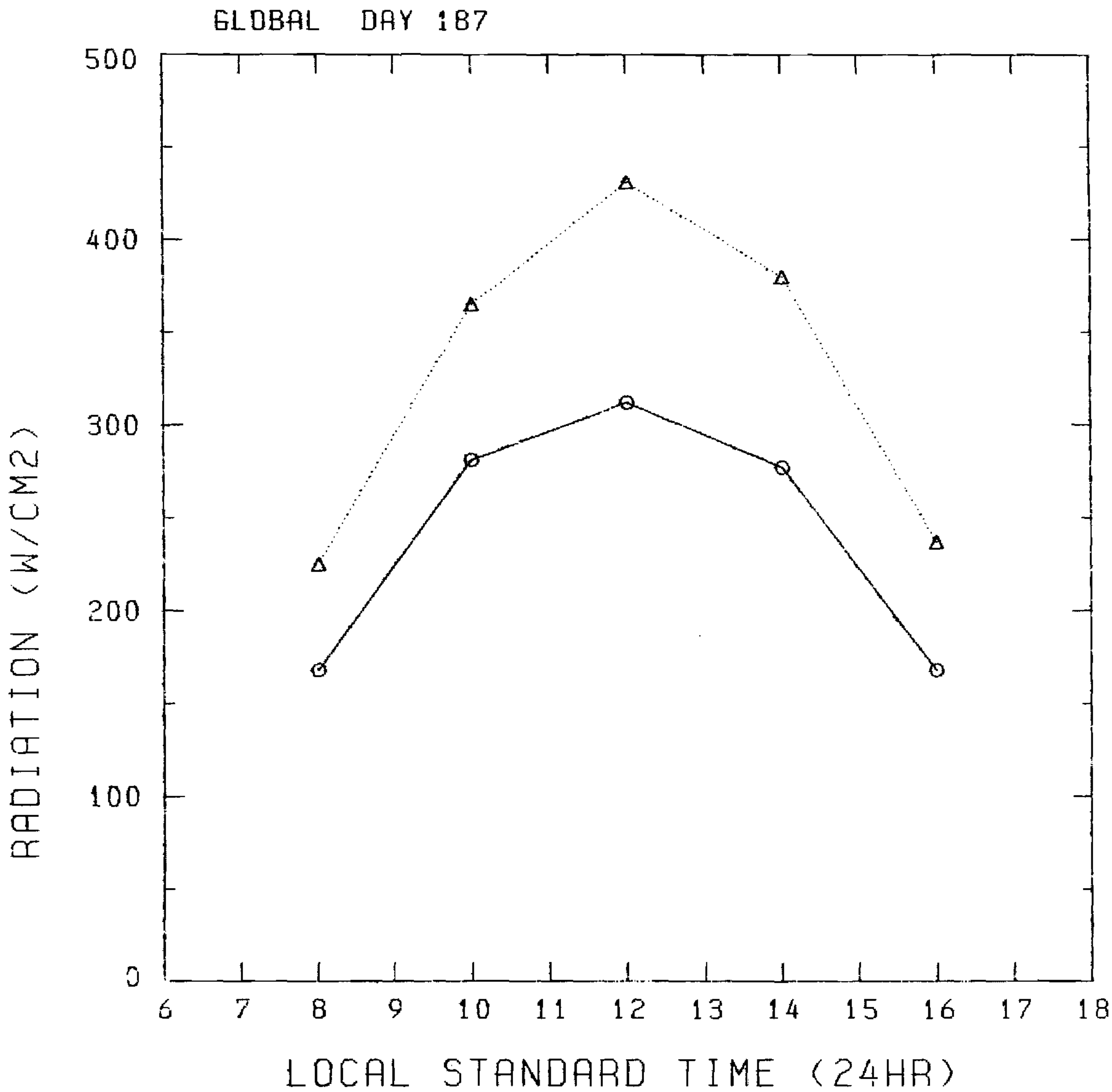

Figure 23. Calculated versus measured Global Radiation on Day 187 (——measured; -------calculated).

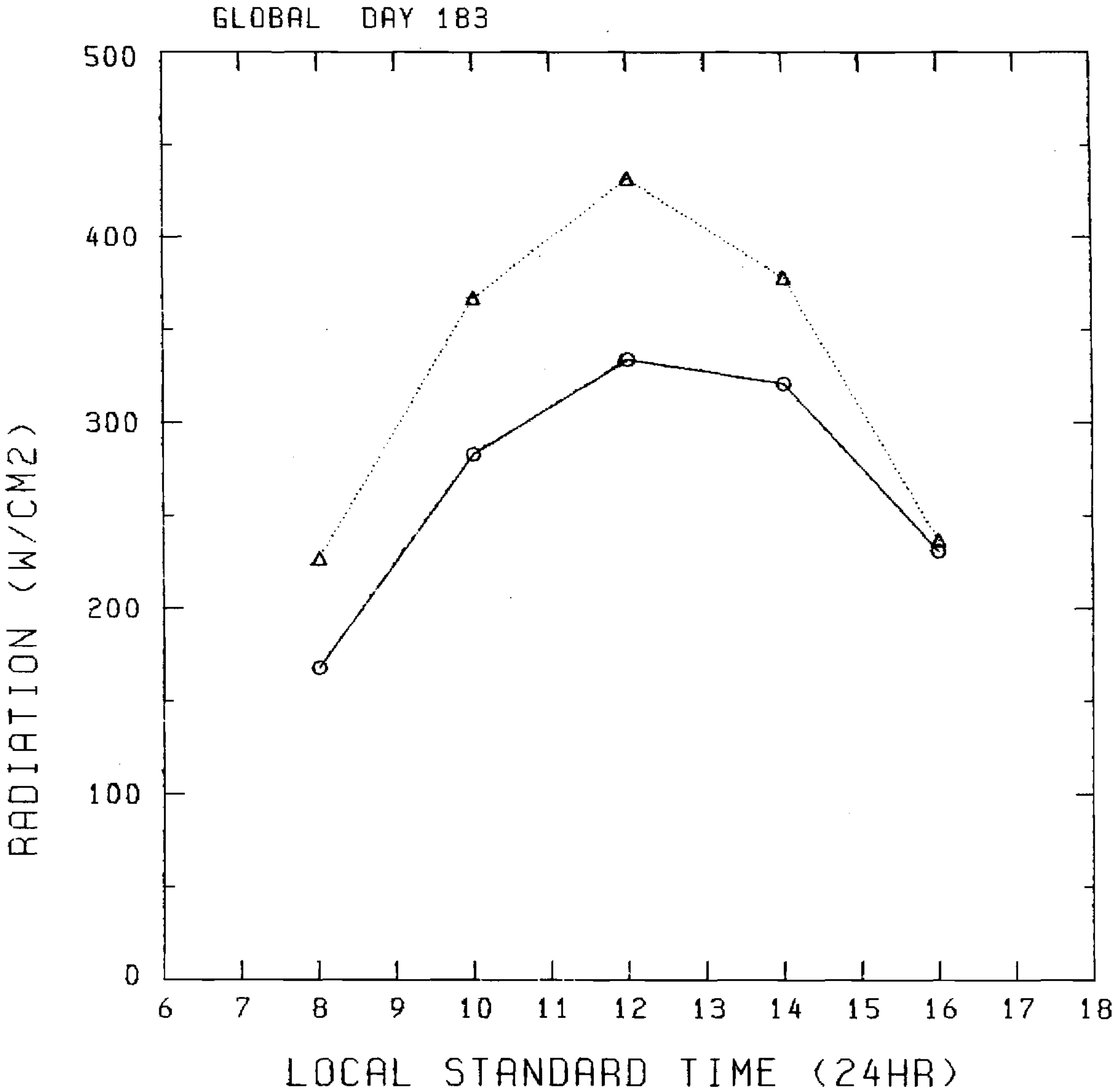

Figure 24. Calculated versus measured Global Radiation on Day 183 (———measured; ------calculated).

Task 2: Collaboration with NOAA and Other National Laboratories

Collaboration with National Laboratories has included interaction with the NOAA Laboratories in Boulder, Colorado and Rockville, Maryland, the Solar Energy Research Institute (SERI) in Golden, Colorado, and the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. Interaction with the NOAA Laboratory in Boulder has been primarily through talks with Dr. John J. DeLuisi of the NOAA-ARL GMCC group. Dr. DeLuisi suggested the investigation of the characteristics of UV-erythma radiation as a worthwhile research project. Some past work in this area was passed on to this author (Machta et al., 1975; Machta, Hass, and Cotton, 1977; DeLuisi and Harris, 1981) and the author was made aware of an existing data base of such UV measurements. A preliminary review of the literature seems to indicate that the subject has some interest and that some problems in the area may be attacked by the methods applied in the present project without considerable modification. A review of the available literature is continuing.

Further talks concerning UV-erythma radiation were initiated with Dr. Gerald Cotton of NOAA-ARL Laboratory in Rockville, Maryland. One week was spent at this facility discussing with Dr. Cotton and Dr. Lester Machta the UV-erythma radiation data base archived by Dr. Cotton. Discussions centered around the nature of the data base, the quality of the data, the availability of the data and possible uses of the data. In between discussions with Drs. Cotton and Machta, the author took the opportunity to visit with other members of the Laboratory staff. The short talks and visits enlightened the author to other research being conducted at the Laboratory and broadened his view of the Laboratory and NOAA in general. While at the Laboratory, the author attended a seminar on the climatic effects of the El Chichon volcanic debris injected into the atmosphere given by Dr. Machta and attended by NOAA personnel from throughout the Washington metropolitan area.

A shorter visit was made to the NOAA Laboratory in Boulder, Colorado in November 1983 to attend a meeting concerned with observational evidence of the effects of the El Chichon dust clouds on radiation values received at the surface. This meeting was attended by members of the DOE Solar Energy University Sites and by members of the Boulder Laboratory concerned with radiation measurements. Other groups monitoring solar radiation were also represented including the National Weather Service and Battelle.

Collaboration with the Solar Energy Research Institute (SERI) continues through information and data exchanges. This interaction has resulted in one scientific publication to date (Bird et al., 1983) and input on two proposals is submitted. One proposal is aimed at acquiring a portable spectroradiometric system for obtaining solar apectra. Acquisition of this instrument would allow the author to continue the work initiated at SERI and to expand the research to other areas. A visit to SERI was made in November 1982 to discuss in detail with Dr. Richard Bird the proposed research with the spectroradiometric systems and to solicit his input on specifications for the instrument.

Collaboration with NCAR took place in the form of a visit in November 1982 to discuss possible research interaction during the summer months. Discussions with Dr. John Firor of the Advanced Study Program (ASP), Dr. Paulette Middleton of the Environmental and Societal Impacts Group of ASP, and Dr. Warren Washington of the Global Climate Modeling Group of the Atmospheric Analysis and Prediction Division took place. The nature of these talks were to discuss mechanisms whereby young scientists and possibly an accompanying student (graduate or undergraduates) could come to NCAR and learn about the reserach being conducted there. A mechanism exists for established research which corresponds very closely with on-going research in one of the Divisions at NCAR. This mechanism requires strong ties with members of the Division. A second mechanism exists for graduate students through

NCAR's Graduate Assistantship Program. There is no formal mechanism for young scientists with limited research experience or for scientists with research interests not strongly pursued in one of the Divisions. What is being sought by the author is a means of allowing college professors to pursue a research project in the atmospheric sciences, possibly with a student, during the summer and to continue that project during the following academic year at their own institutions. Close collaboration with an NCAR scientist would continue throughout the period of the project. The disadvantage of this type of program is that it would be of little direct benefit to NCAR in the first year when it would not be expected that the new researchers would contribute much to the research effort. However, it does have good potential of producing good contributions during the succeeding years and such a program could enhance significantly the amount of atmospheric research at four-year colleges.

Interactions with NCAR also included discussions with Mr. David Armstead who coordinates the Summer Employment Program at NCAR. Mechanisms to get more students in the traditional disciplines (physics, chemistry, mathematics, engineering) to pursue careers in the atmospheric sciences were discussed. Ways of allowing a faculty advisor to accompany a summer student continues to be a topic of discussion.

Task 3: Interaction with Regional Colleges

Interaction with regional colleges included visits to Georgia Southern College in Statesboro, Georgia and Savannah State in Savannah, Georgia in November 1981, a visit to the Atlanta University Center complex in Atlanta Georgia, a second visit to Jackson State University in Jackson, Mississippi in March 1982, and a visit to West Georgia College in Carrollton, Georgia in May 1982. A team of scientists and staff members of the School of Geophysical Sciences at Georgia Tech traveled with our Mobile Atmospheric Research Vehicle (MARV) to the aforementioned institutions putting on short courses, demonstrating the research capabilities of MARV, and making contact with faculty and students. The author's primary responsibility was to demonstrate the research capabilities of MARV. A description of MARV and its instrumentation is given in Table 2. Two short courses consisting of several lectures were offered: "Urban and Regional View on Air Resources", and "Atmospheric Instrumentation and Data Interpretation." The author delivered the lecture "Boundary Layer Research: Instrumentation, Data and Usage" in the second short course. The purpose of the visits was to foster interest in the atmospheric sciences among the faculty and students, to promote the development of joint research projects, and to attract quality students to the field of atmospheric science. The response to the visits and short course lectures has been encouraging.

Further interaction with regional colleges has included the teaching of courses at Morehouse College in the Atlanta University Center complex and at Jackson State University. The courses taught are listed in Table 3. These courses were taught in tandem with Dr. Luther F. Roland, also of the School of Geophysical Sciences at Georgia Tech.

Table 2. Georgia Tech Mobile Atmospheric Research Vehicle

INSTRUMENTATION:

AMBIENT INSTRUMENTATION RESEARCH TS-2A TETHERSONDE

A tethered balloon system to measure profiles of wind speed, wind direction, temperature, humidity and pressure to heights of 800 m (2,600 ft.). The system, with free balloon AIRSONDE package and theodolite, can measure atmospheric parameters to 10 km (30,000 ft).

SOLAR RADIATION MONITORING INSTRUMENTS

Eppley normal incidence pyrheliometer (NIP) for direct beam solar radiation; Eppley precision spectral pyranometer (PSP) for global (all sky) radiation; Eppley PSP for global radiation on tilted surface; Swissteco (CSIRO) funk radiometer for net radiation (visible and IR); Li-Cor Solar Meter/Integrator (LI-175) for global radiation.

CLIMET METEOROLOGICAL SYSTEM

On 20 ft. Van Mast: wind speed, wind direction, temperature, humidity and pressure instrumentation.

LIDAR

Compact flash lamp-pumped dye laser system with minicomputer to analyze laser echoes from atmospheric haze and cloud layers, display results on graphics terminals, and record data on magnetic tape for more detailed analysis on larger computers. Measures aerosol concentration versus altitude.

CLIMET PARTICLE ANALYZER

Measures number of particles per unit volume in 6 size ranges ranging from 0.3 to 10 μm radius.

THE VEHICLE:

An 837 ft^3 custom-designed atmospheric sampling van with 126 sq. ft. of floor space. The laboratory space is environmentally controlled, and has fluorescent lighting. Power for operating the equipment can be either external powerline or a built-in gasoline powered generator.

Table 3. Schedule of Courses Taught

Course Title	Courses Taught At	Credit Hours
Intro. to Physical Meteorology	Morehouse College	3 semester credit hours
General Meteorology 1	Jackson State University	3 semester credit hours
General Meteorology 2	Jackson State University	4 semester credit hours
Atmospheric Thermodynamics	Jackson State University	3 semester credit hours

The General Meteorology 1 class taught at Jackson State University was quite interesting and unique since it included high school science teachers as students. Hence, this course provided us the opportunity to stimulate interest in the atmospheric sciences and provide means of incorporating atmospheric science into the science curriculum and instruction at the secondary level. Student exposure to the field of atmospheric science by the secondary level is vital if one hopes to significantly increase minority participation in this area. Such courses serve as a good starting point for initiating an exposure mechanism, but much more interaction with educators is needed to adequately address the issue of early exposure of students to the atmospheric sciences.

A third type of interaction with regional colleges has been the development of an undergraduate research program in the earth and atmospheric sciences at the Atlanta University Center. This program, under the direction of the author, will provide year-round research opportunities for juniors and seniors who wish to study atmospheric science. Research projects will be chosen from on-going research projects of the faculty of the School of Geophysical Sciences at Georgia Tech. Student stipends would be provided through a grant from the National Science Foundation.

This program consists of a summer component and an academic year component. Both components consist of a research activity enhanced by an instructional activity. The specific objectives of this program are:

1) to stimulate student interest in the earth and atmospheric sciences;
2) to provide students with research experience in the earth and atmospheric sciences;
3) to acquaint students with careers and scientists in the earth and atmospheric sciences; and
4) to help develop the skills needed for successful graduate study.

Student participants in this program would serve as good choices for research assistants for young faculty members who may not have access to graduate research assistants.

Task 4: Development of Expertise and Experience in the Use of Satellite Data

The original proposal requested funding for a two-year project. Funding was received for a project duration of one year. This change in funding level caused us to re-evaluate our plans and we have placed less emphasis on this particular task. However, this task has not been abandoned and some progress has been made. The author participated in a course (Geo.S. 8133: Atmospheric Data Analysis) concerned with inversion techniques in remote sensing and indirect measurements with specific applications to data derived from satellite platforms. Moreover, magnetic tapes of GOES data have been obtained and GOES photographic data is received on a regular basis.

REFERENCES

Bird, Richard E. and R.L. Hulstrom, 1980: Direct Insolation Models, SERI/TR-335-344, Solar Energy Research Institute, Golden, Colorado.

Bird, R.E., R.L. Hulstrom, and L.J. Lewis, 1983: Terrestrial Solar Spectral Data Sets, Solar Energy, 30, 563-573.

Braslau, N. and J.V. Dave, 1973: Effect of Aerosols on the Transfer of Solar Energy Through Realistic Model Atmospheres, Part I: Non-absorbing Aerosols. J. Appl. Met., 12, 601-615.

Dave, J.V. and J. Gazdag, 1970: A Modified Fourier Transform Method for Multiple Scattering Calculations in a Plane Parallel Mie Atmosphere, Appl. Opt., 9, 1457-1465.

DeLuisi, John J. and Joyce M. Harris, 1981: "Characteristics of Ultraviolet Radiation in the Human Erythema Band Measured with a Robertson-Berger Meter and a Double Monochrometer", NOAA Technical Memorandum ERL ARL-99 Air Resources Laboratory, National Oceanic and Atmospheric Administration, Silver Springs, Maryland.

Gautier, C., G. Dick and S. Masse, 1980: A Simple Physical Model to Estimate Incident Solar Radiation at the Surface from GOES Satellite Data, J. Appl. Met., 19, 1005-1012.

Hatfield, J.L., R.B. Giorgis, Jr., and R.G. Flocchini, 1981: "A Simple Solar Radiation Model for Computing Direct and Diffuse Spectral Fluxes," Solar Energy, 27, No. 4, 323-329.

Hiser, H.W. and H.V. Senn, 1980: Mesoscale Mapping of Available Solar Energy at the Earth's Surface by use of Satellites, Solar Energy, 24, 129-141.

Lewis, Lonzy J., 1980: "The Impact of Selected Atmospheric Parameters on Solar Radiation," Doctoral Dissertation, State University of New York at Albany, Albany, New York.

Machta, L., et al., 1975: CIAP Measurements of Solar Ultraviolet Radiation, Interagency Agreement DOT-AS-20082, Climatic Imapct Assessment Program, Department of Transportation, Washington, D.C.

Machta, L., W. Hass, and G. Cotton, 1977: "Relating Spectral and Erythemal UV-B Radiation," unpublished report.

McClatchey, R.A. et al., 1972: Optical Properties of the Atmosphere, 3rd ed., AFCRL 72-0497, AFCRL, Bedford, MA.

Tarpley, J.P., 1979: Estimating Incident Solar Radiation at the Surface from Geostationary Satellite Data, J. Appl. Met., 18, 1172-1181.

Theaekara, J., 1973: Solar Energy Outside the Earth's Atmosphere, Solar Energy, 14, 109-127.